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An assessment of the sustainability and resilience of livelihoods within an Indonesian marine social-ecological system

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Abstract

Indonesia is part of a marine biodiversity hotspot where millions of coastal communities rely on marine resources for food security and livelihoods. The overarching objective of this study is to explore policy interventions that might help small-scale fishing communities in Indonesia to avoid or escape from an undesirable livelihood state. Selayar Island in South Sulawesi was used as a case study where intensive fishing activity occurs at the proximity of marine reserves and presenting problems and responses that are difficult to interpret due to the lack of data for this region. This four-year study used qualitative and quantitative data collection methods and the principles of systems thinking to examine the social-ecological systems that drive trends in the condition of the marine resources and the associated livelihoods.

This research is based on four main activities. First, problem-scoping focus group discussions (FGD, n=12) were held in 2015 in fishing-dominated villages (155 participants) to develop ‘rich pictures’ that help define the consensus and dimensions of the problem. Drawing on the perceived past trends of resources and activities, and problems that receive the greatest attention extracted from the rich pictures, the problem of interest was defined as ‘declining reef fisheries.’ Secondly, in separate months in 2015 and 2016, two series of problem mapping FGDs were held in eight of the fishing villages (~ 230 participants); these involved a group model building activity to capture the ‘mental information’ about the structure of the problematic system (the variables, the direction and polarity of influence between variables, the perceived past and future trends of these variables).

Thirdly, qualitative modelling was done by constructing causal loop diagrams (CLD) to analyse feedback interactions between variables in the system by using the results of problem mapping and a supplementary interview. The CLD identified 26 feedback loops (16 reinforcing and 10 balancing); 13 state variables that normatively define whether the problem is weakening or increasing; and several archetypical systems structures, including ‘fixes that fail’, ‘shifting the burden’, ‘limits to success/growth’, and the ‘tragedy of the commons’. These four outcomes maintained a path-dependence archetype. The feedback generally suggests that a social-ecological trap (SET) is responsible for the ‘declining reef fisheries’ problem in Selayar. Hence, the system is normatively resilient in maintaining an undesirable livelihood state.

Lastly, quantitative modelling was performed using computer-aided stock-and-flow modelling (SFM) for simulating the dynamics of the problem as conceptualised under the archetypes (the base case model). The SFM was constructed using the CLD as a seed structure to represent a generic model of small-scale fishery households (SSFHs) to simulate compound events associated with three types of SSFH that use boats with a smaller or larger motor and target three fish species groups originating from four habitats. The base case was defined by optimistic (ideal) estimates of ecological parameters mainly based on proxy information, as well as social parameters mainly based on recent household survey datasets and grey literature. The 30-year base case projections from the year 2016 suggest that, under business-as-usual conditions, Selayar's SSFHs could become 'locked' in an undesirable livelihood regime: maintaining profitable fishing operations would become infeasible under declining resources, and result in sub-par household living standards.

Three policy interventions were then modelled and applied to the base case model, including: improvement of the alternative occupation (Policy-1), surveillance of destructive fishing (Policy-2), and marketing of local fish landing (Policy-3). As an individual intervention, Policy-1 generates higher household incomes and a lesser number of fishers, but leads to an increased fishing effort among the remainder of the fishers, including destructive groups; Policy-2 led to a reduction in destructive fishers and a higher fish catch rate, but the improved income stream remains below the living standard; Policy-3 resulted in a more profitable fishery overall, although it led to local habitat degradation and fish depletion. Modelling demonstrated that these trade-offs could be avoided if policies are implemented together (i.e., the 'Strategy'). The Strategy model promotes long-term livelihood state trajectories that avoid SET through avoiding episodes of household financial crisis and at the same time the maintenance of local fishing activity without eroding local fish stock.

In summary, this study expands the available data and demonstrates that desirably resilient livelihood systems based on SSF are possible with a combination of policy interventions. Due to the degree of uncertainty in the dynamic model assumptions and parameters, one should exercise careful consideration when adopting the model output values (mainly the threshold points) when systems would become qualitatively different. This study will be useful to researchers/practitioners interested in developing the model to reflect conditions at finer spatial and temporal resolutions or further researching the system component or processes in order to fill the research gap, with particular reference to the Selayar Island context.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Publications included in this thesis

No publications included.

Submitted manuscripts included in this thesis

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Other publications during candidature

No other publications.

Contributions by others to the thesis

Contributor	Statement of contribution
Siham Afatta Kemal Taruc	Conception and design (90%) Analysis and interpretation (85%) Drafting and production (85%)
Carl Smith	Conception and design (10%) Analysis and interpretation (5%) Drafting and production (5%)
Ove Hoegh-Guldberg	Conception and design (0%) Analysis and interpretation (5%) Drafting and production (5%)
Ingrid van Putten	Conception and design (0%) Analysis and interpretation (5%) Drafting and production (5%)
Novie Andri Setianto, Suryo Kusumo	Data collection during problem mapping focus group discussions in Chapter 5 (50%), Collation of information and pre-existing dataset from grey literature as part of model parameterization in Chapter 6 (30%)
Russell Richards	Development of the ‘draft’ stock-and-flow model using Stella® Architect software in Chapter 6 (50%)

Contributor	Statement of contribution
Amanda Lindsay	Data collection for the Bio-LEWIE household survey in Chapter 6 (100%) Statistical summarizing of the Bio-LEWIE household survey dataset in Chapter 6 (50%)

Statement of parts of the thesis submitted to qualify for the award of another degree

No works submitted towards another degree have been included in this thesis.

Research Involving Human or Animal Subjects

Due to the requirement for human participation in this study, Institutional Human Research Ethics Approval was granted by the University of Queensland's Behavioural & Social Sciences Ethical Review Committee (BSSERC) representative on 11th May 2015 (Approval number 2015000582) to the Capturing Coral Reef and Related Ecosystem Services Project (CCRES) where I was involved as one of the co-investigators. A copy of the ethics approval letter is included in 0.

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Keywords

indonesia, natural resource management, social-ecological systems, rural livelihoods, small-scale fisheries, systems thinking, systems dynamics, resilience, sustainability, social-ecological trap

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Dedications

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List of Abbreviations

ACM	Adaptive co-management
AL	Amanda Lindsay
AP	Andi Penrang
BLT	*Bantuan Langsung Tunai* / Direct cash aid
BOTG	Behaviour-over-time graph
BPS	*Badan Pusat Statistik* / Central Bureau of Statistics (of Indonesia)
CAS	Complex adaptive systems
CC	Carrying capacity
CCRES	Capturing Coral Reef and Related Ecosystem Services
CM-SES	Coastal and marine social-ecological systems
COREMAP-CTI	Coral Reef Rehabilitation and Management Program- Coral Triangle Initiative
CPUE	Catch per unit effort
CS	Dr Carl Smith
DS	Destructive fishery dimension element
EN	Larger-engined boat dimension element
FAO	Food and Agricultural Organization of the United Nations
FGD	Focus group discussion
FH	Fishing household
FHH	Fishing household consumers dimension element
FM	Female dimension element
GMB	Group model building
GUI	Graphical user interface
HP	Horsepower
HR	Herbivorous fish dimension element
IDR	Indonesian Rupiah
IPB	*Institut Pertanian Bogor /* The Bogor Agricultural University
JICA	Japan International Cooperation Agency
KOMNASKAJISKAN	National Commission of Fisheries Resources Assessment
LG	Large mangrove tree dimension element
LK	Dr Luky Adrianto
MD	Middle-age dimension element
ML	Male population dimension element
MMAF	Ministry of Marine Affairs and Fisheries

MN	Mangrove habitat dimension element
NEN	Smaller-/no-engine boat dimension element
NHH	Non-fishing household consumer dimension element
NS	Dr Novie Setianto
OL	Older age dimension element
PG	Pelagic fish habitat dimension element
PNPM-MKP	The National Program of Self-Supporting Marine and Fisheries Community Empowerment
PR	Predatory fish dimension element
RF	Coral reef habitat dimension element
RR	Dr Russell Richards
SD	Systems dynamics
SEAFDEC	Southeast Asian Fisheries Development Center
SES	Social-ecological systems
SESAMME	Socio-ecological systems application for mental model elicitation
SESF	Social-ecological systems framework
SET	Social-ecological trap
SF	Squid/pelagic fishery dimension element
SFD	Stock-and-flow diagram
SFM	Stock-and-flow model
SG	Seagrass habitat dimension element
SK	Dr Suryo Kusumo
SLA	Sustainable livelihoods approach
SM	Small mangrove tree dimension element
SQ	Squid/fast-reproducing fish dimension element
SSFH	Small-scale fishery household
ST	Systems thinking
STM	Systems thinking and modelling
TR	Traditional fishery dimension element
UQ	The University of Queensland
YN	Young age dimension element

Chapter 1 Introduction

1.1 This research

This research aims to inform academics as well as government, civil society, and business institutions in general, who are endeavouring to align coastal livelihood activities and marine resource management. The research topic was prompted by the findings of my MPhil dissertation in 2011 which examined the management of a marine protected area in Indonesia – part of a collaborative project between the Coral Reef Ecosystems Lab at the University of Queensland (UQ) and Diponegoro University in Central Java. The findings brought my attention to the intricate linkage between the effectiveness of interventions to control disturbances to coral reef ecosystems and the livelihood strategies adopted by communities living adjacent to a marine conservation area. This led to further discussions in 2012 with researchers at the Global Change Institute at UQ, which set out another research agenda in Indonesia linked to the Capturing Coral Reef and Ecosystem Service[1] (CCRES) project. The linkage marked the beginning of this challenging study of coastal livelihood systems, which required me to deal with multi-stakeholder and multi-knowledge settings in order to understand the marine social-ecological system.

This thesis focuses on the mismatch between marine resource use and conservation in Indonesia. In general, it is also relevant to marine resource management problems of most human-dominated coastal areas with high conservation values in other tropical developing countries. The research draws on systems thinking where it views the pressures from resource use activities (or, livelihoods) as systems constructed of reciprocal interactions between human and natural components. It consolidates sources of information such as numerical and written databases including information stored in the minds of stakeholders and uses this information to model processes, fluxes and feedback interactions among system components defining a livelihood system(s) extracted from a data-poor environment. The thesis seeks to operationalise the emerging and widely studied concept of resilience by assessing the impact of alternative policies – as alternative feedback structures and different thresholds in the system – that may enhance or diminish livelihood system adaptability to future social and ecological conditions. In doing so, the research seeks to address gaps in the knowledge regarding the management of tropical marine social-ecological systems`. This includes identifying site-sensitive livelihood solutions that allow greater adaptation of resource users to cope with potentially adverse changes in future conditions

[1] http://www.gci.uq.edu.au/projects/capturing-coral-reef-related-ecosystem-services

and, at the same time, greater flexibility for transforming livelihood strategies to reduce resource use and allow ecosystems to recover.

1.2 Background to the research problem

The mismatch between the use and the conservation of coastal and marine ecosystem resources is a compelling problem in Indonesia. Indonesia is part of the ‘Coral Triangle’, a marine biodiversity hotspot where millions of coastal communities rely on marine resources for food security and livelihoods (Hoegh-Guldberg et al. 2009; Hoeksema 2007). However, the way these communities use marine resources in the region is degrading the marine environment on which their livelihoods depend. The alarming degradation and depletion of marine resources in Indonesia is jeopardising the wellbeing of these marine-dependent communities.

1.2.1 Impacts of historical overfishing on marine-dependent livelihoods

In Indonesia, the failure of wild fish stock to recover has been one indication of overharvesting (or, ‘overfishing’) (Pauly 1987). The state-published reports on the Indonesian marine capture fisheries statistics show a slowing in the annual increase in total wild fish catch between 1987 and 2011 (MMAF 2013; Purwanto 1999). Between 2007 and 2011, the capture fisheries sector was relatively stagnant (yielding around 5 million metric tons annually) compared to the farmed marine products sector (MMAF 2013). In 2011, the Indonesian National Commission of Fisheries Resources Assessment (KOMNASKAJISKAN) reported that a number of economically important demersal, small pelagic, and larger tuna fish species were ‘fully exploited’ or ‘over-exploited’ (MMAF 2013). However, the accuracy of these figures is likely an underestimate of the true level of fisheries exploitation due to the incidence of illegal, unregulated, and unreported fishing in Indonesian waters (Sodik 2009).

Depletion of fisheries in the past has also triggered further harvest intensification predominantly driven by economic motives (or, economic overfishing) (Pauly 1987). Motivated by the desire to regain or maintain a profitable level of catch yield in a shorter-term period, this increased harvest effort efficiency through destructive fishing techniques has a devastating impact on fish habitat. These destructive fishing techniques include blast fishing using homemade bombs to stun or kill fish, which often destroys marine habitat in the benthic areas (e.g., in Southwest Sulawesi) (Pet-Soede & Erdmann 1998a) and the muro-ami fishing technique, which involves diving fishermen trampling on the coral reef to guide fish into the net (e.g., in Central Java) (Marnane et al. 2004)). These techniques often take place even in formally-managed conservation areas (Cullen-Unsworth et al. 2014; Marnane et al. 2004). The physical damage to fish habitats, such as coral reefs, can take years to decades to recover from (Fox et al. 2003). Habitat damage can significantly outweigh any harvest benefit as it creates a loss of nursery ground critical for the regeneration and replenishment of juvenile fish in the longer term (Wilkinson & Salvat 2012).

Fishing operations in Indonesia generally target multiple species using a variety of fishing methods and gear. Accordingly, almost all organisms in the food chain that are economically valuable are under fishing pressure. The targeted and traded fish in Indonesia comprise both long-lived and short-lived species; piscivorous, planktivorous, and invertebrate species; and bottom and pelagic species (White et al. 2013). Furthermore, overfishing has also been linked to the disruption of fish species growth and recruitment, which has led to a reduction in the average wild fish species biomass and size, thus, reducing harvest value (Ainsworth, Pitcher & Rotinsulu 2008; Campbell et al. 2014; Pet et al. 2005). This loss of 'productivity' occurs in several fishing grounds that are historically linked to small-scale coastal livelihoods in Indonesia (e.g., Karimunjawa, Raja Ampat, and Komodo islands (Ainsworth, Pitcher & Rotinsulu 2008; Campbell et al. 2014; Pet et al. 2005)).

1.2.2 Impacts of socio-economic factors on marine-dependent livelihoods

The degradation of coastal habitats due to pollution and coastal habitat modification from land-based development over the last five decades has had an additional impact on marine-dependent livelihoods in Indonesia (Edinger et al. 1998; Sloan & Ugandhy 1994). Sediment run-off from deforestation, chemical run-off from poor agricultural practices, and mining and industrial effluents have been detrimental to the health of the coastal environment in both the western and eastern parts of Indonesia (Amin et al. 2009; Edinger et al. 1998; Evans et al. 1995; Powell & Osbeck 2010; Widianarko et al. 2000). The competition between aquaculture, tourism, industry, shipping and ports, and other infrastructure has led to dramatic physical alteration of coastal environments, particularly in populated areas (Bailey & Pomeroy 1996; Eng, Paw & Guarin 1989; Fortes 1988; Wong 1998). This has contributed to the damage of more than 50% of the Indonesian mangrove forests as well as coral reef loss, leaving only 6% of this habitat in 'good' condition (Burke et al. 2002; Spalding, Kainuma & Collins 2010). For these communities, such habitat loss and degradation means reduced protection from storm and water surges that is provided by mangrove forests and coral reefs (Adams et al. 2006; Koch et al. 2009; Nagelkerken et al. 2008).

Population growth due to the migration of fishing communities is another problem in the coastal zone. For example, even in the least populated Indonesian district of Raja Ampat, much of the fishing has shifted away from subsistence to commercial purposes as the population size of villages and small cities increases (Palomares & Heymans 2006). Parallel to the diversification of fishing methods and gear, fishing communities have also expanded the list of target species to include almost all trophic levels from the lowest to highest, including endangered species, such as sea cucumbers, pearls, lobsters, sea turtles, reef fishes, sharks, and tuna (Palomares & Heymans

2006). Furthermore, the remoteness of many regions in Indonesia from the state capital has led to poor formal enforcement and surveillance in direct resource use activity including lack of trust between government officials and local communities (Hill 2008). This has meant that most of the small-scale fishing activity is underreported and unregulated and illegal fishing by foreign vessels is poorly controlled (Varkey et al. 2010).

1.2.3 Impacts to marine-dependent livelihoods originating outside of Indonesia

Forces occurring at the global level are also impacting on marine-based livelihoods within Indonesia. For example, the Indonesian region is experiencing anomalies in sea surface temperatures caused by anthropogenic global atmospheric warming (McLeod et al. 2010; Peñaflor et al. 2009). Events of extreme ocean warming have led to the mortality of reef-building corals (Brown & Suharsono 1990; Rudi et al. 2012) and, therefore, to the habitat of valuable reef fish species (Pratchett et al. 2008). Furthermore, Indonesia is among the areas projected to experience changes in ocean chemistry, such as ocean acidification due to greenhouse gas emissions (Hoegh-Guldberg et al. 2007). Ocean acidification can potentially disrupt the biological development of marine calcifying organisms that build reefs (Hoegh-Guldberg et al. 2007; Sumaila et al. 2011) as well as fish species that reside in coral reefs and other marine habitats (Munday et al. 2009).

Given the globalized fishing industry, international demand for fish in other countries has intensified fish harvests at the local level in Indonesia. For example, demand for international live reef fish in Southeast Asia has meant that certain species, such as the reef grouper, are now targeted by small-scale fishermen due to its high demand (Koeshendrajana & Hartono 2006). However, live reef fishing in Indonesia also involves destructive practices such as coral-damaging cyanide fishing (Mous et al. 2000). As mature reef fish stocks are depleted, temporary floating fish cages are commonly used to capture and grow juvenile fish, allowing them to develop to profitable body size (Elliott et al. 2001; Pomeroy, Parks & Balboa 2006). This has caused local pollution due to the untreated aquaculture waste, and the loss of food for other wild fish species that feed on these fish (Pomeroy, Parks & Balboa 2006).

1.2.4 Social responses to marine-dependent livelihood impacts

There are approximately 251 million people in Indonesia (CIA 2013), about 28 million of whom are living in poverty (a number greater than the population of Australia in 2012). Most of this population is concentrated in the rural coastal areas of Indonesia (BPS 2014; Haeruman 1988; White et al. 2005). There are around 2.7 million fishing labourers in Indonesia and in 2012 they harvested IDR 70 trillion (AU$ 7.2 billion, AU$ 1 = 9.700) worth of fisheries products from marine capture fisheries (MMAF 2013). Around 80% of this harvest was contributed by small-scale fishing activity (MMAF 2013). Small-scale fishing is generally decentralized, near-shore, using fishing vessels that are often less than 10 gross tonnes (GT) and traditional fishing gear. Most small-scale fishing is for subsistence but there may be some commercial component (SEAFDEC 2003). Despite the economic value of the harvest, poverty is ingrained in Indonesia's fishing-dependent communities (Stanford et al. 2014). Persistent poverty is, on the other hand, another complex problem that can be caused by both material- (e.g., low income, debt trap, natural resource scarcity) and non-material (e.g., lack of education, social exclusion, entitlement failure, political disempowerment) factors (Fisher & Christopher 2007; Reardon & Vosti 1995; Smith, Khoa & Lorenzen 2005).

The synergies of these social and ecological vulnerabilities make small-scale fishing a high-risk occupation in Indonesia (e.g., fishing despite bad weather) (Suhari 2014). Fishing is part of the traditional culture in many coastal communities and is complemented by other seasonal non-extractive occupations, such as marine farming, tourism work or migrant work in urban areas (e.g., in Karimunjawa, Indonesia (Taruc 2011) and Madagascar (Cinner, Fuentes & Randriamahazo 2009)). Most fishing labourers do not obtain direct added value from the processing of fish products since the majority of small-scale fishermen sell their harvest raw (Kontan 2013). Growth in the processing and canning industry has also been impeded by high supply uncertainty, which affects profitability and investment interest (Handoyo 2014). The majority of fish processing enterprises in Indonesia are small-scale, and the top 50 commercial canning companies in Indonesia are operating at only 60% capacity (Handoyo 2014).

With the aim of alleviating poverty and improving employment opportunity of underprivileged fishing communities, in 2009 the Ministry of Marine Affairs and Fisheries launched the National Program of Self-Supporting Marine and Fisheries Community Empowerment' (PNPM-MKP[2]). Among the activities in the program was the provision of unconditional cash transfer (*bantuan langsung tunai*, *or* BLT), which was regulated by district authorities for village-level financing (The World Bank 2012). The funds have largely been used to procure physical livelihood assets, such as fishing gear, boats, housing, and food, or has been distributed directly as grants or short-term micro-loans to stimulate business activities and initiate capacity-building activities (i.e., related to the management of the funds and the livelihood activity) (e.g., Nizar 2015; Tamba & Cipta 2011). However, the report issued by the World Bank[3], the major

[2] MMAF. 2013. Apakah PNPM Mandiri? (= What is the PNPM Mandiri). http://103.7.52.118/pnpm/index.php/arsip/c/2/Apakah-PNPM-Mandiri-/?category_id=1 22 August 2015. Ministry of Marine Affairs and Fisheries of Indonesia.

[3] World Bank. 2009. *Indonesia - Second Program Nasional Pemberdayaan Masyarakat (PNPM) Rural Project*. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/2009/01/10149506/indonesia-second-program-nasional-pemberdayaan-masyarakat-pnpm-rural-project

lender for this project, acknowledges that BLT was under public debate regarding its "effectiveness" and "appropriateness" because (1) households "…would not receive the skills or awareness encouraging them to pull themselves out of poverty."; (2) "… would become dependent on handouts, less likely to find work, and more likely to misspend... [the funds] … for non-productive goods…"; and (3) the "cash handout" was prone to political motivation and manipulation as the process did not endure "…governance protocols and automatic procedures…" (The World Bank 2012). A similar situation has been discussed in other studies (e.g., Agrawal and Redford (2006); Béné and Friend (2011)) which argue that material and monetary support may not address the broader systemic problems underlying persistent poverty in coastal communities. In particular, for small-scale fisheries, these problems can include a lack of financial education, technological innovation, capital ownership, access to markets, marketing and financial institutions, or unfair harvest pricing and revenue sharing arrangements (Béné, Macfadyen & Allison 2007).

The mutual interaction between ecological (e.g., fish species depletion, habitat loss) and social (e.g., systemic poverty-related issues) problems can further reinforce dependence on an already vulnerable livelihood and an unsustainable fishing strategy. For example, to maintain catch targets or profitability of fishing operations, fishers use harvesting methods that are highly efficient and yet damaging to fish habitat and health (Pet-Soede & Erdmann 1998b). These damaging fishing methods continue despite fishers knowing that both fish and habitat are being exhausted (Halim 2002). Access to less harvested fishing grounds requires higher operating costs, and this means that fishers borrow money, thereby creating a debt trap for fishing-dependent households that only reinforces their dependence on fishing (Halim 2002; Pet-Soede et al. 2001). Small-scale fishers in Indonesia are also at the mercy of middlemen for cash loans in order to pay for fuel or to rent boats (Halim 2002). The fishers then sell their fish to these middlemen to repay their loans, with the middlemen controlling the sale price of fish (Halim 2002; Radjawali 2012). As a result, small-scale fishers might not receive a fair price for their fish while the middlemen make the bulk of the money (Radjawali 2012).

1.2.5 Addressing the research problem as a social-ecological system

Undesirable relationships that exist between humans and natural systems in small-scale marine fisheries in Indonesia can be described as a 'social-ecological trap' (e.g., Cinner (2011); SRC (2012); Steneck et al. (2011)). This trap is caused by an amplifying feedback cycle that results in many small-scale fishers being trapped within vulnerable and unsustainable livelihoods. Overcoming social-ecological traps requires an understanding of the 'social-ecological systems'

(SES) that create the trap, which can be used to identify interventions that to break or weaken the trap (Holling 2001). In turn, understanding SES requires the use of systems thinking, which is the study of interactions among system components and how they influences system behaviour (Jackson 2003). Therefore, a systems perspective is critical to understanding problems in fisheries since, as a livelihood, fishing embodies a system construct where the interaction of both human- and nature-related assets, processes, histories, trends and shocks are shaping livelihood activities, and outcomes (Allison & Ellis 2001).

Despite the persisting symptoms of an interrelated human-environment problem, state-led management of coastal and marine resources in Indonesia is predominantly separated into social and biological objectives. Some research attributes the state's inability to control overfishing in conservation areas to the lack of understanding of, or refusal to acknowledge, the underlying social, cultural, or economic problems (Clifton 2013; Ferrol-Schulte et al. 2013). As a result, coastal communities might have resisted or ignored marine conservation policies because they conflict with their immediate and often uncompromising livelihood needs (Viswanathan et al. 1997; Winter & May 2001). In circumstances where community resource use is considered illegal due to marine conservation policies, distrust between communities and managers can develop and communities respond by evading or disregarding the law (Viswanathan et al. 1997).

Addressing problems involving SES and the associated CAS characteristic highlights the importance of operationalizing the resilience approach in the design of problem interventions (Armitage et al. 2012). A similar concern applies to facilitating communities to escape or avoid the social-ecological trap in small-scale coastal livelihoods (Kittinger et al. 2013). Improving livelihood 'resilience', as opposed to 'vulnerability', theoretically means improving "the capacity of a [livelihood] system to absorb [social and ecological] disturbance and to undergo change while still retaining essentially the same function, structure, identity, and feedbacks" (Walker et al. 2004, p. 4). There has been a rapid evolution of the conceptual framework of resilience for assessing problematic systems (e.g., Nelson, Adger and Brown (2007); RA (2007); Walker et al. (2006)). However, operationalizing resilience to assess SES problems remains a challenge related to barriers to understanding complexity (including the availability of ecological and socio-economic information) and dynamics (i.e., unpredictable response behaviour of both social and biological systems linked to heterogeneity in system structure and pattern) (Biggs et al. 2015; Rogers et al. 2013). Viewed from a research perspective, the main practical challenges include determining which variable to measure and developing methods to measure them so as to observe system resilience, thresholds, and fast- and slow-variables accurately (Ifejika Speranza, Wiesmann & Rist 2014; RA 2007).

1.2.6 Study site: Selayar Regency, South Sulawesi Province, Indonesia

The research described in this thesis is focused on Selayar Island and Gusung Pasi Island, which are two of the 26 inhabited islands that are part of the 132 islands in the regency (or, *Kabupaten*) that is also named Selayar (Figure 1-1). The two sites were chosen after the stakeholder workshop between the COREMAP-CTI[4] and CCRES project members held in early July 2014. At that time, the two islands were considered among the least investigated focal research sites of the COREMAP-CTI national program. The regency consists of 1,188.28 km2 of mainland area and 21,138.41 km2 of sea waters, or approximately 95% of the total area (BPS 2015). As of 2017, the regency's population is approximately 133,033 (BPS 2018), and the government has an annual budget of about IDR 900 billion per year which equates to approximately IDR 6.7 million per person (BPS 2018). Agriculture, including fishery (~26,000 workers) is the main livelihood sector of the regency, followed by the services (~12,000 workers) and industry (~5,000 workers) (BPS 2015). Fishing activity in the region involves small- to medium-scale economic activities of fishers within and outside Selayar. Fishing fleets using a mixture of non-engine boats (~1100 units), outboard motor boats (~2600 units) or boats with a medium-to-large onboard engine (~3000) were found to be operating in 2014 (DKP Selayar 2014). Diverse fishing methods and gear are used by fishers, ranging from lift nets, gill nets, handlines, traps, and fish aggregating devices (mainly artisanally operated), to seine nets, purse-seine nets, and muro-ami (some engine-assisted) (DKP Selayar 2014). Around 16 hectares of mangroves and 33,000 hectares of coral reefs are situated in the regency with about 4,300 hectares of the area established as a district-based marine protected area[5].

Selayar Island is the 'main' island of the regency since it is the centre for governmental and public administration activities and where more than 65% of the regency's population (~84,000) resides (BPS 2018). There are about 33,300 households spread across the 11 districts (or, *kecamatan*) of the Selayar Regency with an average household member of 4 (BPS 2018). The majority of the households (~21,300) are located in the Selayar and Gusung Pasi Islands (BPS 2018) which are predominantly rural, but also feature several semi-urban village settings. The female population is slightly higher than that of the males, whereby, on average, there are approximately 92 males for every 100 females (BPS 2018). Around 13% of the population (~17,000 people) are living below the poverty line, and more than11,000 households are unable to fulfil their basic needs ('pre-prosperous' families) or are only able to fulfil basic needs other than socio-psychological needs ('prosperous 1' families (BPS 2018). Educational institutions from the

[4] Coral Reef Rehabilitation and Management Program – Coral Triangle Initiative: http://coremap.or.id/
[5] Selayar Regency Marine Protected Area Profile: http://kkji.kp3k.kkp.go.id/index.php/en/marine-protected-area-data/details/7/93

elementary up to the senior high school level (including vocational high school) are available within the regency and most are locate on Selayar Island. Accordingly, tertiary education is one of the main reasons young adults move away from the island. Until 2017, only one hospital has been established in the Selayar Regency and is located in the Bontoharu subdistrict, which is supported by 14 public health centres, and 289 maternal and child health centres distributed accross whole Kepulauan Selayar Regency (BPS 2018). Upper respiratory tract infection is the dominant health problem in the region (BPS 2018), partly due to the prevalence of first- and second-hand smoking in the community.

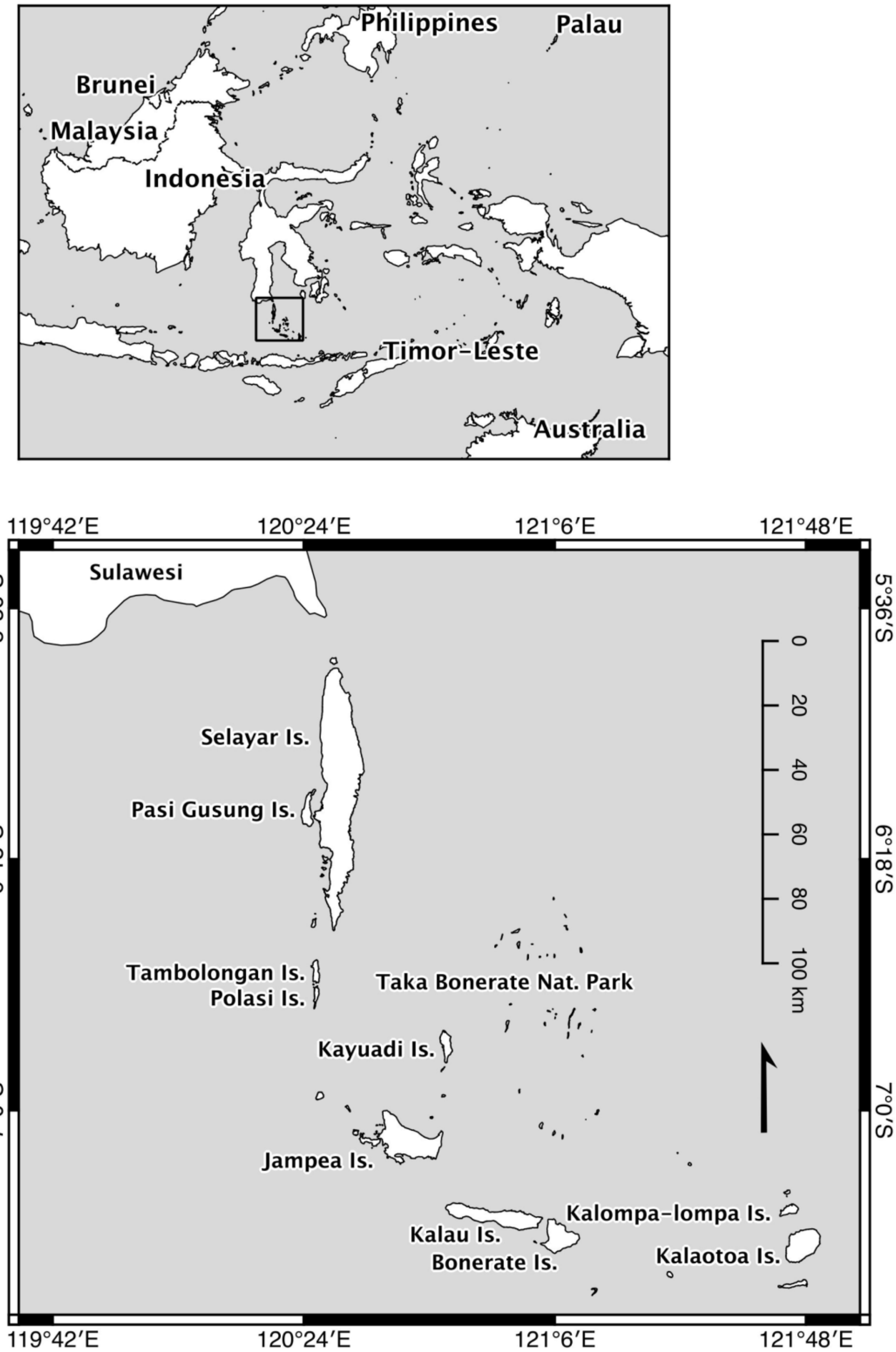

Figure 1-1. The geographic location of the Selayar and Pasi Gusung islands in South Sulawesi, Indonesia.

1.3 Overarching objective and method

The overarching objective of this research is to explore the types of interventions that might help small-scale fishery-based livelihoods in the communities of a marine managed area in Indonesia to enable citizens to avoid, prevent or escape from an undesirable state such the social-ecological trap. The overarching method is to use Selayar Island as a case study and collect relevant data that was analysed using the systems thinking approach and methodologies. Specifically, the research is set out according to several main methods with the aim of understanding the investigated social-ecological systems, the key drivers and causal relationships that drive trends in the use and condition of marine resources, and the likely impacts of different policies in terms of their potential to improve the sustainability of the local community and marine ecosystems. The main assessments and the associated key questions are presented in Section 2.4 in the next chapter.

1.4 Research Significance

The research focuses on the problem of managing coastal and marine social-ecological systems (CM-SES) such as those that exist within human-dominated priority marine conservation areas in Indonesia. The problem is related to the mismatch between marine natural resource stakeholder efforts to utilize marine ecosystem products and services, and to preserve or manage marine resources. A major challenge in addressing the problem is that solutions that are introduced to address community wellbeing problems are considered separate from those of the environment, and vice versa. Hence this research is significant in that it provides a better understanding of the coupled relationships between livelihood systems and systems surrounding natural resources, and particulary the local-level system daynamics that underlies the problem.

1.5 Outline of the Thesis

The thesis is divided into eight chapters. After this introduction, a literature review in Chapter 2 contextualises the research by demonstrating the linkage between the problems of marine resource use and management, systems thinking, and the concepts related to system resilience, which has implications for the proposed conceptual framework and key questions. Chapter 3 discusses the research design and the methodological framework, based on a ‘soft’ and ‘hard’ systems approach for the data collection, and the six main activities in this research. Chapter 4 presents the results and analysis from the problem scoping FGDs (Activity 1) which were held to establish the problem of interest. Chapter 5 analyses the data from the participatory problem mapping (Activity 2), the causal modelling (Activity 3), and the supplementary interview (Activity 4) as part of Main Assessment 1. Chapter 6 presents the results and analysis from the computer-aided dynamic modelling (Activity 5) and secondary information collation (Activity 6), as part of Main Assessment 2. Chapter 7 presents the results and analysis from the testing of the proposed policies/strategies defined in Chapter 5 using the computer-based model developed in Chapter 6. In Chapter 8, I recapitulate the major findings of this research and propose issues for future research.

Chapter 2 Conceptual understanding of the problem

2.1 Coupled social-ecological interaction underlying livelihood vulnerability

2.1.1 Human livelihood and marine environment

The term ‘livelihood’ refers to “means of support or subsistence” (Merriam-Webster 2014). In the formal Bahasa Indonesia, the word is translated as “pencaharian” – an alteration of ‘cahari’ or ‘cari’ that mean “to seek”, which denotes “job” or “profession” (KBBI 2014). Asking lay people about the meaning of the term ‘livelihood’ would likely result in different personal interpretations. This research supports the working definition suggested by Chambers and Conway (1992, p. 6), which is:

> A livelihood comprises the capabilities, assets [including both material and social resources] and activities required for a means of living: A livelihood is sustainable when it can cope with and recover from stress and shocks, maintain or enhance its capabilities, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at local and global levels and in the short and long term [not undermining the natural resource base].

In Asia, the development of communities in societal terms is historically inseparable from the marine environment. In Indonesia, for example, Chinese naval records have shown that socio-economic activities such as coastal and maritime trading have been sustaining livelihoods of naval kingdoms in the region as early as the 7th century (Rausa-Gomez 1967). During the medieval era and up until the colonial period, fishing in Indonesia has largely been practised for subsistence or small-scale commercial activities, such as barter and inter-island trade (Bailey, Dwiponggo & Marahudin 1987). Before World War II (WWII), the globalization and industrialization of the natural resource economy in Indonesia has largely concerned with the land-based natural assets, such as those related to the agricultural sector (Huff & Angeles 2011). The colonial economy has largely taken part in the intensification of the collection and global shipment of natural resources such as the agricultural commodities (Huff & Angeles 2011). After WWII, the South-East Asian region experienced a rapid increase in population, with Indonesia being among the most notable (Hirschman 1994). However, since then, natural assets have been exploited by economic activities as though inexhaustible, with devastating consequences for the region’s biodiversity (Falkus 1990; Sodhi et al. 2004). This has included the industrialization of marine fisheries in the region, contributed to by technological advances, such as motorized vessels and more effective fishing gear, which has enabled further and more frequent fishing trips as well as an increase in fish landings (Morgan & Staples 2006).

Globally, more than one billion people in coastal communities (i.e., those living within 50 km of the coast) depend on coastal and marine ecosystem services, mainly for food and for the support of livelihoods and the economy (Mora et al. 2013). These countries, such as those in Asia, are where the world's largest number of fishers and fish farmers resides (FAO 2014). The coastal area in the tropics may include ecosystems such as mangrove forests, marshes, tide flats, and coral reefs. The global economic benefit from a single ecosystem such as the coral reef is estimated to reach US$29.8 billion annually given its value for fisheries, coastal protection, tourism, and biodiversity (Cesar, Burke & Pet-Soede 2003). A study by Costanza et al. (1997) estimated the monetary value of global coastal and marine ecosystem services to be at least US$ 20 trillion annually. In low-income (hereafter 'developing' (IMF 2014)) countries, fish food is an essential and most traded commodity. In 2012, the fish trade from these countries contributed net-export revenue up to US$ 35.3 billion – a value higher than the agricultural commodities in the same year (FAO 2014). These numbers are yet an underestimation given the non-material benefits of the ecosystem, such as cultural heritage and identity (e.g., spiritual, religious, aesthetic), cognitive (e.g., education and research), which are highly varied and difficult to understand and measure (Millennium Ecosystem Assessment 2005a); as well as vast amounts of unreported data such as due to illegal, unregulated, unreported fishing (FAO 2014).

Of the world's coastal community dwellers, it is estimated that between 470 and 870 million reside in developing countries (Mora et al. 2013). In some countries, populations in coastal regions are projected to grow at significantly faster rates than their inland counterparts (Neumann et al. 2015). Fishing is being adopted as a key livelihood strategy by many coastal communities in developing regions (Stobutzki, Silvestre & Garces 2006), and particularly those in rural areas. In 2004, the FAO reported that 90% of the 38 million fishing and fish-farmer populations documented are categorised as 'small-scale' (FAO 2004b). The small-scale capture fisheries from one fisheries sub-sector alone account for about half of the global fisheries production and supplies of fish primarily intended for human consumption (FAO 2005). For a number of developing countries in Asian, African, and Latin American regions, the small-scale fisheries sector provides considerable economic benefits at the national (i.e., contribution to gross domestic product and of foreign exchange from international market trade), local (i.e., main driver of rural economy, income and employment buffer from small-scale harvest, such as fishing and farming, and directly related post-harvest activities, such as processing, trading, ancillary services), household and individual levels (i.e., direct earnings from fish sales and self-consumption of fish) (World Bank 2008).

The term 'small-scale' has a diverse and dynamic meaning as there is no standard definition, in part due to governments and organizations intermittently changing the classification of activities

(World Bank 2008). Adapting to the FAO (2004a) *in* Béné, Macfadyen and Allison (2007), this research defines ‘small-scale’ fishing as activities that involve several characteristics such as:

(1) Labour-intensive employment;
(2) harvesting, processing, or distribution technologies to exploit marine resources;
(3) full-time, part-time, or seasonal occupation;
(4) supplying fish and fishery products to local and domestic markets, and for subsistence consumption;
(5) production for export purpose, where feasible;
(6) both men and women engaged in fishing, processing, marketing and/or distribution activity;
(7) additional employment and income opportunities form ancillary activities (e.g., net making, boat building, engine repair and maintenance, etc.); and
(8) wide operations at various organizational levels that are heterogeneous across countries and regions (e.g., self-employed single operators, informal micro-enterprises, formal sector businesses).

2.1.2 The social-ecological vulnerability of coastal communities in developing countries

The livelihoods of the coastal communities in developing countries are considered most vulnerable given many are dependent on an already depleted marine resource (Stobutzki, Silvestre & Garces 2006). The global trend on the use of coastal and marine ecosystem services has triggered environmental pressures ,mainly through overexploitation, pollution, population increase, and economic growth, land-use change, invasive species, and climate change; and these are increasing significantly (Millennium Ecosystem Assessment 2005a). These anthropogenic drivers cause undesirable changes to vital marine resources that occur on a local (e.g., fish species stock depletion, fish habitat damage (Edinger et al. 1998; Maynard et al. 2008)) broader level (e.g., disruption of the fish’s natural demographic pattern, increasing frequency and magnitude of coral bleaching (Hoegh-Guldberg et al. 2007; Sumaila et al. 2011)). This adds to the existing livelihood risks associated with natural coastal phenomena (e.g., hurricanes, tsunamis, earthquakes).

Unless there is a substantial mitigation effort on the part of human society, undesirable anthropogenic and environmental changes are projected to continue (Millennium Ecosystem Assessment 2005c). Avoiding and minimising the social and ecological repercussions from these environmental changes to the already vulnerable livelihood of these communities is a serious future concern (Millennium Ecosystem Assessment 2005c).

The high dependence of livelihoods on already limited natural resources has exacerbated a number of environmental problems, such as pollution, degradation, and resource overuse. These environmental consequences are seldom individually premeditated, but are rather an outcome influenced by the cumulative effect of individual attitudes towards the state[6] of the ecosystem asset (e.g., degraded marine resources) or a more fundamental set of problems within the social system (Kollmuss & Agyeman 2002). Poverty is one socioeconomic problem that has a profound influence on the current global biodiversity crisis (Fisher & Christopher 2007). In the small-scale fisheries discourse, poverty can be seen as a multi-dimensional problem as it involves not only cash income deprivation but also the loss of security, opportunity and disempowerment related to employment, livelihood assets, health, education and decision-making processes (Jentoft & Eide 2011). A considerable proportion of the poverty-stricken population in developing countries resides in coastal areas. In Indonesia, for example, around 25% of its 28.5 million poor communities (~7.8 million) are in the coastal rural areas (BPS 2014; TNP2K 2011).

2.1.3 Path-dependent process and social-ecological trap in livelihood

In a theoretical review of four history-sociological studies of the agricultural and fisheries system, Boonstra and de Boer (2014) observe that a path-dependent process (see Figure 2-1) is instrumental in the ‘locking’ of livelihood into a social-ecologically vulnerable state. Referring on Mahoney (2000), a path-dependent process involves (1) past event(s) that are contingent on circumstances (social- or ecological- related); (2) the events trigger a succeeding sequence (e.g., pattern of social behaviour or chain of events); and (3) the sequence manifests in a self-reinforcing behaviour (i.e., reproduced over time) which cannot be explained on the basis of past events, or ‘antecedent conditions’.

In their examination of one historical and three contemporary social studies, Boonstra and de Boer (2014) identify that the rigidity (i.e., resistance to change) of livelihood is influenced by both macro- and micro-level circumstances where ‘macro’ refers to collective outcomes of mechanisms contributed by the ‘micro’, which refers to human or nature entities at a lesser (or single) number. These mechanisms can also interact interdependently either as antecedent conditions or a legacy condition (Boonstra & de Boer 2014). Furthermore, rigidity manifests when an undesirable antecedent condition is reinforced by the response of human actors or by nature entity (Boonstra & de Boer 2014). These responses can be intentionally and/or unintentionally actuated, such as when a human actor has limited options for mitigating the antecedent conditions and, at the same time, they are restricted selection process (at a point of event or time, or, ‘critical juncture’) or when

[6] Here, ‘state’ refers to a particular condition in a specific time

ecological thresholds regulate the way nature responds (Boonstra & de Boer 2014). The next section of my thesis discusses an example of a 'trap' in coastal livelihoods, where a path-dependent process involving a maladaptive human response maintains episodes of reproduction antecedent conditions.

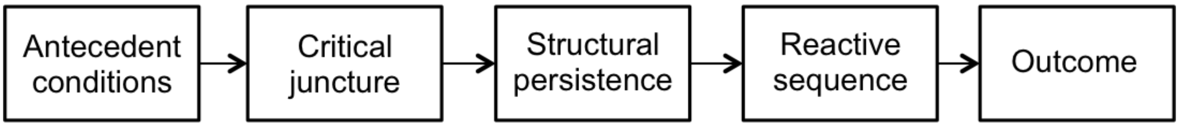

Figure 2-1. A diagram describing the structure of a path-dependent process (Mahoney (2001) emerging from past social and ecological conditions that define the available livelihood options and influence actors' selection processes (antecedent conditions). This is followed by the selection of particular livelihood options from existing alternatives (critical juncture). Production, as well as the reproduction of the trap, then follows (structural persistence). The reactive sequence includes the reactions and counter-reactions that augment the trap situation (outcome).

In developing regions, poverty-stricken individuals or households often coexist and interact with social circumstances occurring at the community level or higher (Lang 2007). Some of these circumstances are also barriers to marine natural resource management, such as weak institutional frameworks, a lack of alternative strategies for adaptation, social conflicts, poor management capacity and resources; and lack of political will (Pomeroy & Andrew 2011; Weeratunge et al. 2013). The feedbacks between poverty and other social circumstances can further create "social traps" which Platt (1973, p. 1) refers to undesirable situations where individuals, communities or societies are caught in a "… direction or some set of relationships that later prove to be unpleasant or lethal and that they see no easy way to back out of or to avoid." The poverty trap itself referred to as a "… situation in which poor people are unable to mobilize the necessary resources to overcome either shocks or chronic low-income situations and are trapped in stable or increasing poverty" (Cinner, Daw & McClanahan 2009, p. 128). More recently, several authors proposed the idea of a "social-ecological trap" (SET) (e.g., Cinner (2011); SRC (2012); Steneck et al. (2011)) that explicitly includes nature systems, alongside human systems, in feedback interactions that are shaping an undesirable state of systems relationship that is often persistent to change. From the SETs observed in the case studies of livelihood systems (e.g, Boonstra and de Boer (2014); Boonstra and Hanh (2014); Cinner (2011); Cumming (2017); Purdy, Kinch and Hadley (2015)), this feedback mainly involves undesirable social/ecological condition(s) that promote the coping mechanisms of the natural resource users, however, through socio-economic activities/strategies that are maladaptive by means of reinforcing or maintaining the corresponding undesirable condition.

In societies dependent on terrestrial as well as marine resources, socio-economic maladaptation can generate a 'low value' system and at the same time an 'impoverished' system, hence, an entrapment. For example, a study in north-eastern Tanzania that traced the 50-year development of agriculture systems found that trajectory farm-ecosystem dynamics have been shaping the degradation of off-farm ecosystem services and yet agricultural yield remains low, and the farmers remain poor (Enfors 2013). Enfors (2013) found that the farmers' livelihood was 'locked' in putting more pressure on another ecosystem beyond the farm ("off-farm") in order to increase productivity despite frequent crop failures. This dilemmatic dependency is difficult to change since opportunities for livelihood diversification are almost negligible due to a combination of degraded off-farm ecosystems and water shortages from increasing dry spells (Enfors 2013).

Similarly, case studies of marine fisheries systems in the developing regions (e.g., Indian Ocean (Cinner & David 2011) and Southeast Asia (Armitage & Marschke 2013)) suggested that coastal communities that engaged at a subsistence or small-scale economic level, in particular, were incentivized to remain operating in fisheries despite declining biophysical resources. In other cases, fishers employ destructive methods that are potentially accelerating the loss of an already depleted species population and its habitat, although it might not necessarily maintain or improve their socio-economic benefit from fishing (Cinner 2010). The synergy of institutional, social and biophysical dynamics is implicated in trapping small-scale fishers in this undesirable livelihood pattern. These include institutional factors, such as ill-defined resource ownership and entitlements to harvest ("open-access"); social factors, such as poverty, stakeholder conflicts and high levels of cultural heterogeneity (Béné, Macfadyen & Allison 2007; Jentoft & Eide 2011); and ecological factors, such as mobility of marine species, increasing frequency and unpredictability of extreme natural events, and uncertain biophysical conditions (Butler et al. 2014; Cinner, J et al. 2013; William W. L. Cheung 2008).

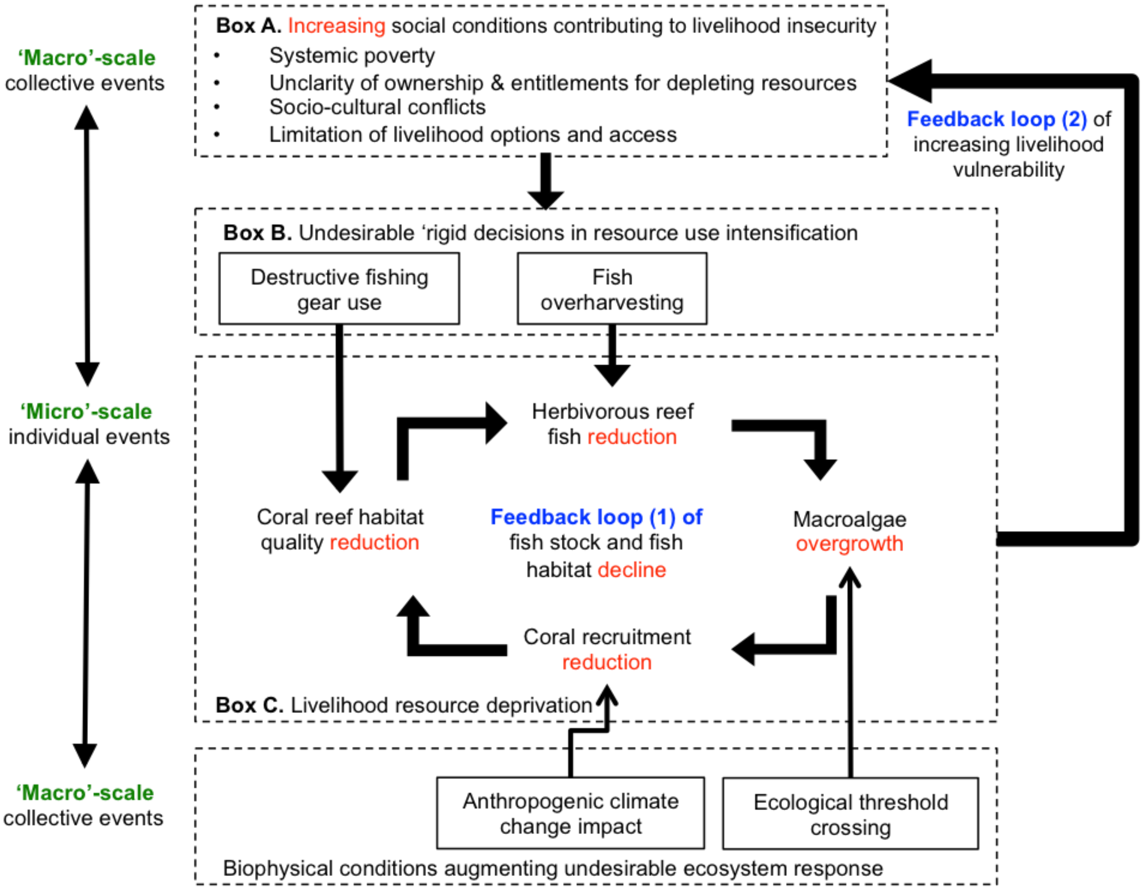

Figure 2-2. Diagram illustrating causal mechanisms that underlie social-ecological trap. The interaction between social and ecological processes across different scales (green text) catalyse feedback mechanisms that reinforce cycles of declining fish stock and coral reef habitat (feedback loop 1), and promote livelihood insecurity and natural resource overuse (feedback loop 2). The cycles are 'vicious' as they involve the dynamics of reactions and counter-reactions (positive and negative signs) reproducing conditions that characterise the 'trap' (Box A, B, & C). (Adapted from Cinner (2011)).

2.2 Livelihood from the perspective of social-ecological systems

2.2.1 Natural resource-based livelihood as a social-ecological system

The concept of social-ecological systems (SES) has been used by many scholars to emphasize the interdependence and interaction between human and nature underpinning the problem of unsustainable trajectory of development in coastal areas (e.g., marine reserve management: Pollnac et al. (2010), maintenance of marine ecosystem service: Hughes et al. (2005), coral reef-related livelihoods: Cinner (2011), small-scale fisheries: Kittinger et al. (2013), Indonesia cases: Glaeser and Glaser (2010), Ferrol-Schulte et al. (2013)). Specifically, the concept frames unsustainable livelihood development as a result of coupled processes between different human actions that are reducing ecological capacity to generate its essential services; and the associated ecosystem responses that, in turn, affect livelihoods, creating vulnerability, and compromising human security (Ferrol-Schulte et al. 2013). The conception of SES supports that create and maintain the prosperity of society and the ecosystem requires solutions that recognize the link between social, economic, and ecological systems coherently and integrate the technical or scientific problems, rather than treating them as independent, isolated issues (Ostrom 2009). Although they have similar meanings, there are several working definitions of SES, including:

- "An SES consists of a bio-geo-physical unit and its associated social actors and institutions." (Glaser, Krause, et al. 2012).
- "… a system composed of organized assemblages of humans and non-human life forms in a spatially determined geophysical setting." (Halliday & Glaser 2011).
- "An SES is an ecological system intricately linked with and affected by one or more social systems." (Anderies, Janssen & Ostrom 2004).
- "[SES is a] nested, multilevel systems that provide essential services to society such as the supply of food, fibre, energy, and drinking water." (Berkes, Folke & Colding 2000).

The improved understanding of SES has been partly enabled by analyses of coastal resource management in tropical developing regions (e.g., in Africa: Cinner et al. (2009); McClanahan et al. (2011), Brazil: Berkes and Seixas (2005); Nayak, Oliveira and Berkes (2014), Oceania: Aswani (2011); Aswani and Hamilton (2004), Indonesia: Cinner et al. (2006); Glaeser and Glaser (2010). Case studies of problems linked to small-scale marine-dependent livelihoods also demanded integrative and interdisciplinary research frameworks capable of explicitly accommodating both human- and nature-centred examinations (e.g., the sustainable livelihood approach (SLA): Allison and Ellis (2001); Scoones (1998); social-ecological systems framework (SESF): Ostrom (2009); the driver, pressure, state, impact, response framework: Mangi, Roberts and Rodwell (2007)). Conceptually, livelihood can be positioned in the 'lower-tier' and examined as part of the subset of processes or variables that defines a focal SES at a larger level (e.g., Millennium Ecosystem Assessment (2005b)). Or, it may be positioned in the 'higher-tier', where livelihood is the focal system comprising smaller subsets of mainly human and natural resource variables, human institutional processes, and ecosystem processes that influence resource use and livelihood strategies (e.g., Ferrol-Schulte et al. (2013)). Accordingly, a conceptual complementarity can be distinguished such as between SLA and SESF (Figure 2-3).

Based on the framework comparison by Binder et al. (2013) both the SLA (Scoones 1998) and SESF (Ostrom 2009) embrace a systems perspective because the diagnostic of the problem warrants the examination of undesirable impacts resulting from both environmental and social changes (i.e., the 'vulnerability context'; see texts in red in Figure 2-3), which determines the boundary of the livelihood or SES being investigated. Furthermore, both frameworks acknowledge a system trait such as complex interactions (arrows in Figure 2-3) between different SESF subsets (i.e., boxes in Box A, Figure 2-3) and between SLA subsets (i.e., boxes in Box B). Also, each subset of the SESF is relatable to a particular subset of the SLA, indicated by texts and boxes in green, orange, blue, and brown. Similarly, the components of each SLA subset (i.e., boxes in Box B, Figure 2-3) are relatable to those of the SESF subsets (i.e., boxes in Box A) as the components mainly represent human and natural resource units, and their interactions and outcomes. Both frameworks have also been useful in studying problems involving the relationship between human and marine environments. For example, the review by Ferrol-Schulte et al. (2013) demonstrated SLA's potential for evaluating persistent and complex problems, such as overfishing and poverty, which are associated with SESs in tropical coastal and marine regions. Likewise, the work of Partelow (2015) highlighted the operability of SESF in understanding small-scale fishery management problems.

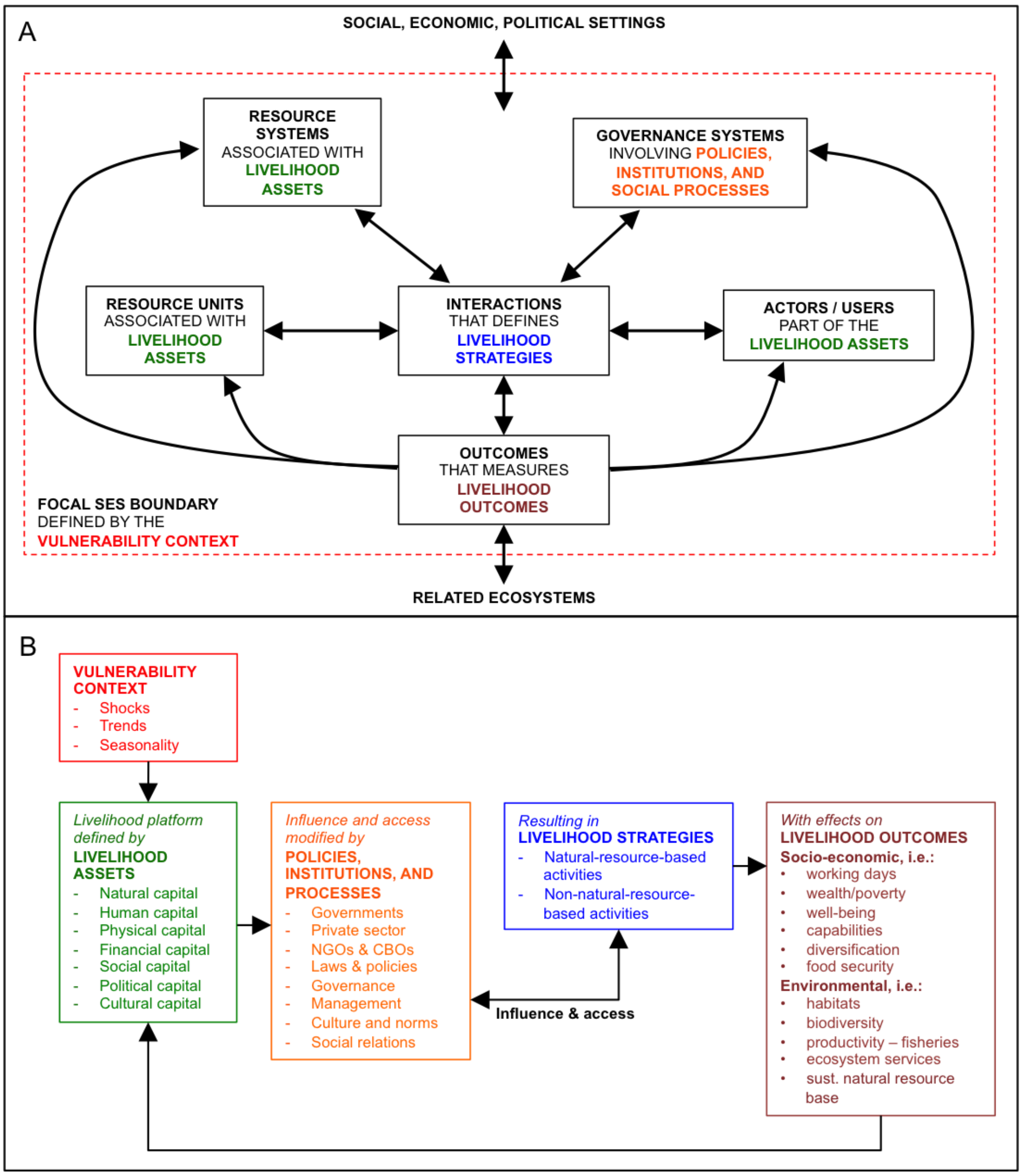

Figure 2-3. Diagram illustrating the complementarity between the Sustainable Livelihood Approach (SLA, in Box A) and the Social-Ecological Systems Framework (SEFS, in Box B). Diagram adapted from Ostrom (2009) and Scoones (1998).

Past discussions and efforts with regards to environmental conservation and human development have focused on the conflicting objectives between livelihood activities and biodiversity conservation (e.g., Budowski (2009); Chapter 1: Brown, Tompkins and Adger (2002)). From a meta-analysis of 39 sites where local conservation efforts concur with economic activities directly dependent on biodiversity, Salafsky and Wollenberg (2000) concluded that the more human actors could comprehend and manifest the linkage between the goals of natural resource preservation and livelihood, the greater the incentive for them (e.g., resource users, policymakers) to preserve the ecosystem. Parallel to this, as asserted by Allison and Horemans (2006) in a review of a small-scale fisheries development program involving 25 West African countries, the sustainability of both biodiversity conservation efforts and livelihood activities depends on its ability to help actors to cope or adapt to both social and ecological changes. Fundamentally, marine-based livelihood systems, particularly fisheries, exhibit the complexity of SES (Mahon, McConney & Roy 2008). Apropos to this, studies suggest that failure to comprehend social-ecological complexity could lead to ineffective interventions to manage marine resource use, thus eroding the success of marine conservation efforts and maintaining existing social coastal problems such as poverty (Christie 2004). Likewise, both formal (i.e., state-led conservation regulations) and informal (i.e., customary conservation rules) marine resource management schemes have a direct impact on coastal livelihoods that may be undesirable (e.g., displacement of fishers due to formal marine reserve: Cinner et al. (2014), unfair distribution of access to resources due to social discrimination: Allen and Garmestani (2015); Armitage, Berkes and Doubleday (2007); Davis and Bailey (1996); Poteete, Janssen and Ostrom (2010)).

2.2.2 SES as a complex adaptive system

Scholars have suggested that the interconnected problems within SES, such as between increasingly vulnerable livelihoods and problematic resource use patterns in the social-ecological trap, encompass the similar characteristics of ‘complex adaptive systems’ (CAS) (Levin et al. 2012; Mahon, McConney & Roy 2008; Rammel, Stagl & Wilfing 2007). The *complex* structure (i.e., the coupled arrangement between different components of social actors and biophysical resources) and boundary setting (i.e., influenced both by social and ecological conditions) of a CAS problem also make a holistic approach in managing a problematic SES inevitably necessary (Holling 2001). Additionally, the way components interact may also involve slow- and fast-changing variables occurring at different levels and scales (i.e., Glaser and Glaeser (2014); Levin et al. (2012)), feedback mechanisms (also see Section 2.2.1) between the variables (i.e., Bueno (2012); Miller, Caplow and Leslie (2012)), and variable threshold levels (i.e., Kinzig et al. (2006); Walker et al. (2006)). This makes SES *adaptive*, given that the system may exhibit self-reorganizing or self-learning capability by the human as well as biological actors, particularly when outside influence is minimal or absent (Buckley 2008; Mahon, McConney & Roy 2008).

Furthermore, these CAS attributes of SES may promote system behaviours that are perpetually changing or ‘dynamic’, as oppose to ‘static’. This applies particularly when the system is coping with, or adapting to, the thresholds being reached with respect to the system variables (Scheffer & Carpenter 2003). The dynamics primarily involve a system response behaviour that has multiple possibilities of non-linear system change trajectories as well as different system state configurations and regimes (Biggs, Carpenter & Brock 2009; Kinzig et al. 2006). The manifestation of these CAS dynamics makes SES subject to high degree of uncertainty and unpredictability, which authors have referred to as ‘emergent properties’ or ‘surprises’(Biggs, Carpenter & Brock 2009; Kinzig et al. 2006). Berkes (2015) describes emergent properties as “… properties of a system that cannot be deduced from the analysis of the parts of the system but can only be understood from the analysis of the system as a whole".

2.2.3 Resilience properties of SES

The resilience concept is increasingly topical and attractive in the examination of SES dynamics alongside the concept of *sustainability* (Derissen, Quaas & Baumgärtner 2011; Xu, Marinova & Guo 2014). The concepts are related, mainly due to the common 'need for persistence'; their application to address coupled human-environment problems, interpreting system capacity for its ability to respond to disturbances, and advocating trans-disciplinary measures are within the overarching problem-solving goal (Angelstam et al. 2013; Hirsch Hadorn et al. 2006; Turner, Matson, et al. 2003; Xu, Marinova & Guo 2014). The term 'sustainability' also has a diverse terminological meaning (Santillo 2007). Similarly, resilience has been sought to coalesce with other concepts such as *vulnerability, adaptability* (or, *adaptation, adaptive capacity*) and *transformability* (e.g., as in Folke et al. (2010); Janssen et al. (2006); Miller et al. (2010); Turner, Kasperson, et al. (2003)) especially in the context of livelihood risks from adverse impact of social/ecological changes (IPCC 2014a). It is acknowledged that these concepts have, for example, semantic and epistemological overlaps with resilience such that each may become part of the meaning, or a unit of objective, or subject of analysis of the other (Folke et al. 2010; Janssen et al. 2006; Miller et al. 2010; Turner, Kasperson, et al. 2003).

On its own, the application of 'resilience' across a range of disciplines has led to a variety of working definitions unique to its application (Brand & Jax 2007). Also, the meaning of resilience has become increasingly vague in various conceptual applications in research (Myers-Smith, Trefry & Swarbrick 2012). Synthesizing the outputs of numerous studies published over the last 35 years, Brand and Jax (2007) reveal that the concept of resilience has evolved as a 'boundary object' which essentially describes terms and meanings that are associated with a concept that, while not strictly defined, is still adaptable and exchangeable across disciplines. Further, as discussed by Carpenter et al. (2001), the operability of the concept requires the system observer to clearly state resilience "of what' (i.e., system of interest) and "… to what?" (i.e., system perturbation, or, the problem of interest).

Given its SES context, following (Walker et al. 2004) and (Resilience Alliance 2002), this research defines resilience as the capacity of a system to absorb disturbance (or hazardous trend or event) and re-organize while undergoing change so as to retain its essential function, structure, identity, and feedbacks. Here, resilience is also being viewed as a normative concept since the retained feedbacks can be induced both by the disturbance or the interventions/policies, and can maintain a system configuration that is either desirable or undesirable to its observers or actors (Abson et al. 2017; Brand & Jax 2007).

The next set of explanations refer to Figure 2-4, which illustrates the maintenance and loss of SES resilience in response to disturbance. Walker et al. (2004) describe the 3 properties of resilience, which are *latitude, resistance,* and *precariousness*. Latitude refers to “the maximum amount the system can be changed [or, experience different system states] before losing its ability to recover [or, when thresholds are crossed]”, which is represented by the width of the basin of attraction (the ‘valley’ between TSx/y and TBy/z, Figure 2-4) (Walker et al. 2004). Resistance refers to “the ease or difficulty of changing the system”, which is the ratio of the depth of basins of attraction versus the width (latitude) in Figure 2-4. Precariousness describes how close the current path of system change is to exceeding the threshold level (TB or TS, Figure 2-4) (Walker et al. 2004).

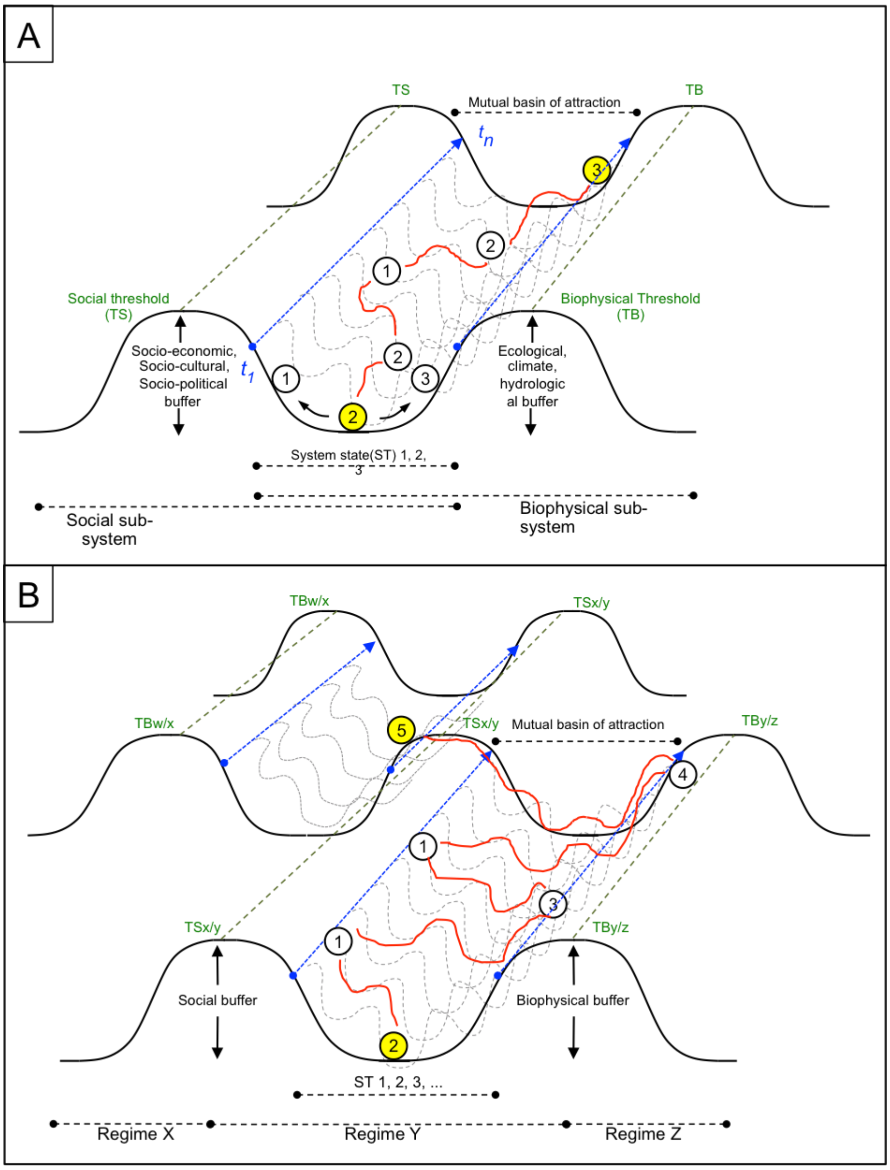

Figure 2-4. A simplified visualization of SES resilience modified from Huber-Sannwald et al. (2012). Box A illustrates a maintained SES resilience. The bell-shaped curves depict the possible domains of the state of the social (left) and biophysical (right) sub-system. Each sub-system's components can buffer unique SES states (ST1, 2, 3) defined by the coupled interaction of the sub-sytem components. In the event of disturbance within the period of t_1 to t_n, the SES adapts by reorganising to different stable states (ST2 -> ST1 -> ST2 -> ST3), which is translatable to system equilibrium dynamics over time, as illustrated in Figure 2-6. Throughout the shifts between alternative states, the particular SES is capable of maintaining its structure, function, and feedback within the mutual basin of attraction of the two sub-systems, whereby the crossing of the social (TS) and biophysical (TB) thresholds are avoided. Figure 2-7 provides an alternative visualization of the systems deviation from the equilibrium state (ST2). Box B illustrates the loss of SES resilience. A combination of external drivers[7] and the decline of social and biophysical capital creates pressure on the social subsystem (ST2 -> ST1). The social response mechanism in ST1 promotes a response trajectory which creates greater higher pressure on the natural resources (ST1 -> ST3). As another episode of disturbance follows, (ST3 -> ST1) social responses gradually push the biophysical system, however, to the critical threshold (ST1-ST4, TBy/z). The degraded biophysical subsystem (ST4) can lead the SES to either continue as a deprived system Regime Y), or promote the social sub-system, transforming it into a new SES (Regime X).

The transition of system states in response to disturbance has largely been observed in natural resource systems (e.g., terrestrial: Jasinski and Payette (2005); Staver, Archibald and Levin (2011); Wood and Bowman (2011), aquatic: Dudgeon et al. (2010); Ibelings et al. (2007); Norström et al. (2009)) and natural resource-dependent livelihood systems: (e.g., coastal: Joseph et al. (2013); Marschke and Berkes (2006); Mills et al. (2011); Sievanen et al. (2005), terrestrial: Bhandari (2013); Cramb et al. (2009); Radel, Schmook and Chowdhury (2010)). In some cases, threshold crossings can lead to an abrupt, large-scale, and dramatic system state shift that isdifficult or impossible to reverse, and they system can enter a new regime (or, "regime shift") that is undesirable (e.g., degradation of basic ecosystem function in coral reefs: deYoung et al. (2008); Hughes et al. (2010), and forest: Lindenmayer et al. (2011); Ripple and Beschta (2006); collapsing fisheries: Pershing et al. (2015) and agriculture: Cumming and Peterson (2017)).

In dealing with these sustainability issues, studies from the coastal and marine SESs, for example, have put forward the importance of embracing non-linear dynamics in the management of SESs (Karr et al. 2015; Klein et al. 2016). This includes exploring possibilities for solution or policy options that are robust, meaning that they are able to tolerate the uncertainties of the system's dynamics while avoiding undesirable outcomes as much as possible (Ferrol-Schulte et al. 2013; Fulton et al. 2011; Mahon, McConney & Roy 2008). However, despite its importance, our understanding of the dynamics of CAS or SES and its influence on system adaptation are still lacking (Carpenter et al. 2009).

2.2.4 Path-dependent processes underlying undesirable lock-ins

The link between the resilience process (Section 2.2.3) and the socio-ecological trap (Section 2.1.3) can also be delineated, as studies have found that feedback mechanisms (from the interactions between social and ecological phenomena) play a role in 'locking' the trajectory of system change towards, or within, the boundary of an undesirable state (e.g., agriculture: Allison and Hobbs (2004); Enfors (2013); Tonts, Plummer and Argent (2014), fisheries: Cinner and David (2011); Steneck et al. (2011)). In systems studies, the path-dependent process also reflects the social notion that 'history matters' (e.g., Section 2.1.3) as it is described as a "…pattern of behaviour in which small, random events early in the history of a system determine the ultimate end state…" (Sterman 2000, p. 349). Path-dependency is also attributable to the resilience concept as it entails irreversibility, such as when a system 'lands' in a new equilibrium state or regime (i.e., 'regime shift', Section 2.2.3). According to Berkes (2015, p. 11) irreversibility asserts the implication of the path-dependence concept in the management of CASs (an attribute additional to self-organization (adaptive), uncertainty, non-linearity and emergence; Section 2.2.3) as it can explain "… how the set of decisions one faces for any given circumstance is limited or shaped by the decisions made in the past, even though past circumstances may no longer be relevant."

Departing from the social system analysis of Mahoney (2000) (Figure 2-1), Sydow, Schreyögg and Koch (2009) explain different phases of feedback interaction that generate path-dependency (Figure 2-5). The authors alternatively referring 'critical juncture' (Figure 2-1) as the first phase ('Phase I', Figure 2-5) when the self-reinforcing cycles are 'unintentionally' created from the interaction of small events. In relation to alternating system states in resilience (Figure 2-4), in the next phase ('Phase II', Figure 2-5) the self-reinforcing processes develops and maintains a pattern or path of change that is, however, 'non-ergodic' or still allowing several system configurations that can be similar to or different from the initial state. The last phase ('Phase III', Figure 2-5) is related to the threshold crossing and regime shift in resilience (Figure 2-4), whereby the lock-in is rendered and a 'new regime' is governing the system as the previous alternative system configuration, or course of change, is no longer manifested.

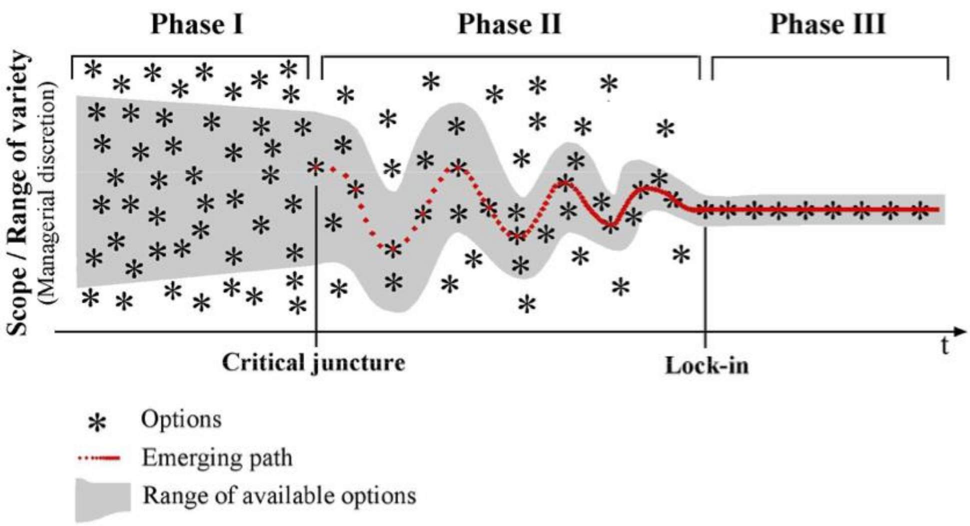

Figure 2-5. An illustration by Sydow, Schreyögg and Koch (2009) of path-dependence in organizational management.

The term 'equilibrium' can refer to the system state, where the ratio between inflow (e.g., force, input) and outflow (e.g., counteracting force, output) is equal (or, zero net change) (Sterman 2000, p. 232). An equilibrium is 'dynamic' when the zero-net change is produced by varying the rate of inflows and outflows, and therefore, the system' keeps changing over time and has an 'average' state (Sterman 2000, p. 232) (Box B, Figure 2-6). An equilibrium can be 'static' when a zero-net change is due to inflows and outflows that are zero, and therefore, there is only one system state exhibited overtime (Sterman 2000, p. 232) (Box A, Figure 2-6). In systems modelling[8], the

[8] This model is a representation of the real-world situation. Modelling is one of the principal approaches in the analysis of systems as an alternative to direct observation, particularly when the latter is not feasible.

state of a system's equilibrium is often defined described by 'state variables', which is one (in a static system) or several variables (in a dynamic system) to portray particular system characteristics (Sterman 2000). In relation to the system's resilience to disturbance (e.g., Section 2.2.3), a stable equilibrium returns to its original state (or average state) after being disturbed, and conversely, an 'unstable' system will move to a new equilibrium state following disturbance (Sterman 2000, p. 129) (Box E, Figure 2-6).

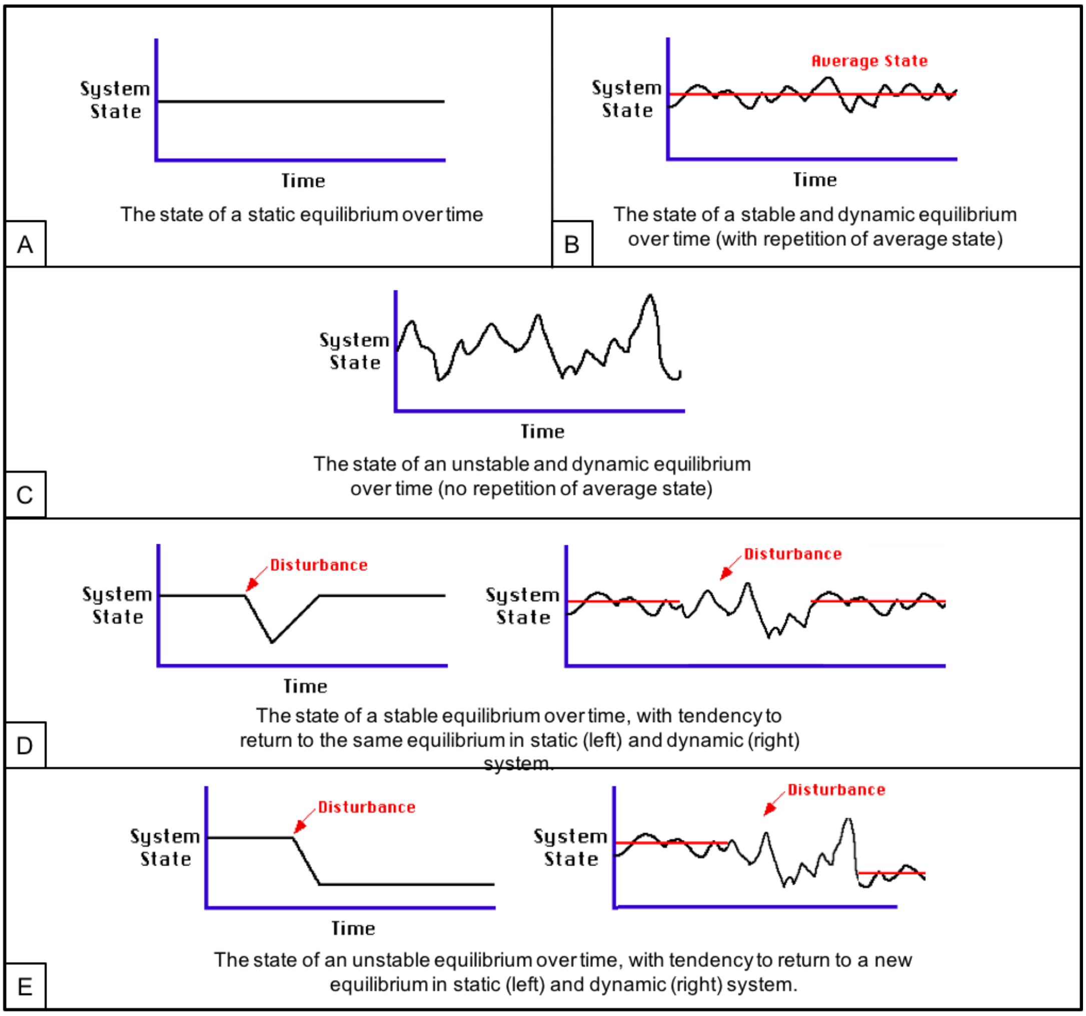

Figure 2-6. Simplified illustrations or representations of different forms of equilibrium adapted from Pidwirny (2006). The X-axis is translatable to the time axis in the resilience process depicted previously (between t_1 to t_n, Figure 2-4).

Moreover, Sterman (2000, p. 351) uses a similar 'valley' and 'hill' (as in Figure 2-4) to illustrate the stable and unstable equilibrium of a system (Figure 2-7). This is illustrated by an

Two main analytical approaches in systems modelling are the 'state-based' and 'scenario-based' approaches. The former primarily involves designing and implementing a mechanistic model that can reproduce the system behaviour(s), particularly those that are undesirable. The latter involves defining various sets of requirements, or parameters, that can produce alternative future system behaviours. These approaches can be contingent upon and complementary to each other, such as in the systems dynamics method (Sterman 2000) equilibrium that is locally unstable yet chiefly governed by several positive feedbacks (Box B, Figure 2-7). Here, the concept of 'locally' unstable' equilibria means that perturbations (the deviations of the system state due to the disturbance events) tend to move and accelerate the system away from the initial equilibrium point, which requires greater force to return to the starting point (as the ball going away from top of the hill, Box B, Figure 2-7) and can cause new dynamics to emerge (new equilibrium: Box E, Figure 2-6); new regime: Box B, Figure 2-4). Positive feedback is a condition where "… the increase of a particular variable [event, condition, etc.] leads to a further increase of this very variable" (Sydow, Schreyögg & Koch 2009, p. 698) and thus, creates a self-reinforcing process. A 'locally stable' equilibrium (Box D, Figure 2-6), on the other hand, occurs when the system is chiefly governed by negative feedbacks (Box A, Figure 2-7). A negative feedback, conversely creates a process that is self-correcting and can "… bring the state of the system in line with a goal or desired state" (Sterman 2000, p. 111). This feedback ensures that there are forces that keep the perturbations small and near the operating equilibrium point (ball eventually rest on the centre of the hill, Box A, Figure 2-7).

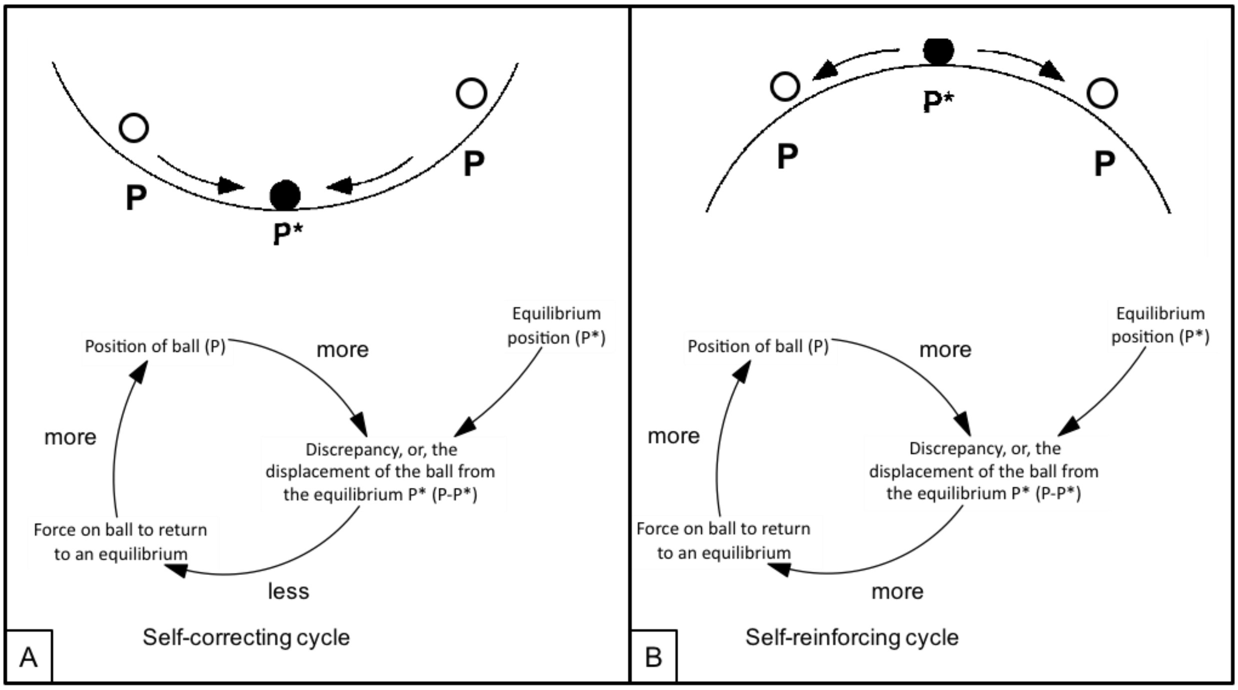

Figure 2-7. Sterman's depiction of a locally stable (A) and unstable equilibrium (B) responding to a disturbance.

The social-ecological trap (Section 2.1.3) and other persistent problematic situations, such as waterways pollution (e.g., Leopold (1981)) or an authoritarian regime (e.g., Nathan (2003)) are, by definition, resilient systems that can be undesirable as they might prevent a society from fulfilling its basic needs. Yet, resilience can be seen as desirable with livelihoods coping and adapting to disasters (Adger et al. 2005), or as a non-collapsible internet system (Hall et al. 2011). In coastal and marine SES, undesirable system changes with indications of path-dependence have been observed. In the biophysical subsystem, for example, a low-resilient (highly sensitive to changes) coral reef that had shifted from coral- to algae-dominated may not return to its original state, even after the previously overfished stock of fishes that control the algae are replenished (Hughes et al. 2007). In this case, the path-dependent process entails discontinuous past disturbance events, both nature- and human-induced, causing ecosystem threshold crossings that reduce coral recoverability (Hoegh-Guldberg et al. 2007; Hughes et al. 2007). In the social sub-system, for example, the decadal influences of the top-down/hierarchical decision-making arrangement reinforced by the control of political elites can shape a highly-centralized marine resource management system (Satria & Matsuda 2004). In this case, the formal system is highly resilient but undesirable as government policies disregard information from traditional/informal institutions, which creates social resistance to policies due to shortfalls in adapting to complex realities in the coastal region (Glaser, Radjawali & Ferse 2010; Satria & Matsida 2016).

2.2.5 Examinations of path-dependence to anticipate system ‘lock-in’-s

In an extensive review on the theory and empirics of path-dependency, Vergne and Durand (2010, p. 736) argue that path-dependency is not yet as ‘well-established’ as empirical evidence, which can “… causally relate identified variables in a systematized manner” is still scarce. The authors also relate this to the understanding of path-dependency as being largely derived from historical case studies (e.g., Section 2.1.3) and, thus, highlight the need for alternative research designs such as computer-aided simulations, experimental studies, and counterfactual investigations to identify mechanisms that can cause (or, avoid) a ‘lock-in’ (Vergne & Durand 2010). In relation to this, several case studies have demonstrated the use of model-based prognosis of path-dependency, to varying degrees, in order to gain insights about the path, timing, behaviour, or rate of a lock-in trajectory (e.g., rural economy: Tonts, Plummer and Argent (2014), terrestrial resource management: Brown et al. (2005), social science: Mollona (2011), industrial management: Aghion et al. (2012).

A simulation assessment of path-dependence by Brown et al. (2005), for example, provides insight into the feedback mechanisms responsible for historical policy resistance of human settlements to development. The agent-modelling study was able to reproduce a historical land-use pattern to assess past residential development that was ‘locked’ in an invariant land-use type (Brown et al. 2005). The results imply that achieving a heterogeneous land-use type requires policy intervention on development that can weaken the feedback interactions between the settlement behaviour of residents and proximity to a service centre (Brown et al. 2005). Another assessment by Aghion et al. (2012) tested the possibility of lowering the resilience of a system state that was perceived to be irreversible, by identifying feedback mechanisms that may increase the system’s susceptibility to change to the desired alternative system state. The author's work on econometric modelling demonstrated that the resilience of the global automotive industry that is currently 'locked' in a fossil-fuel-dependent state can be reduced using policy leverages that may redirect the pattern of technological innovation of companies (Aghion et al. 2012). The results presented by the author show that by reinforcing the interaction between government policies (higher fuel price by cutting government subsidy) and the companies' policies (more investments for clean technology R&D), and promoting increased knowledge sharing between such companies, the growth of the automotive industry would be driven to depend less on fossil-fuel (Aghion et al. 2012).

2.2.6 Barriers to measuring the resilience of SES

The adaptation of an SES to changes or disturbances is different to ecological or physical systems due to the distinctive influence of human actors in foreseeing and deliberating their actions (Armitage et al. 2009; Folke et al. 2005). However, despite the applicability of the resilience concept of improving an actors' level of adaptability via learning SES changes (i.e., the instrumental value and malleability of the concept to guide assessments of subordinate processes or outcomes: sustainability, vulnerability, adaptation, transformation (Section 2.2.3) and path-dependency, normative instrumental value of the resilience concept (Section 2.2.4)), measuring system resilience remains a difficult task when it comes to people. Direct measurements of social, economic, or ecological thresholds can be impractical and uncertain. This relates to the possibility that identifying SES thresholds or buffer variables may be dealing with variables that are not constant (Walker & Meyers 2004) or non-observable due to the fact that the threshold is unknown until it has been crossed (Rogers 2013), or simply due to barriers in obtaining information about the variable (e.g., accessibility or ethical reasons). Measuring system resilience may also require an impractical amount of data collection, which makes the defined threshold levels merely an estimated, or conservative value (Rogers 2013).

Furthermore, it is acknowledged that a threshold database for indicating SES resilience is still limited (Walker & Meyers 2004), although it is growing (Resilience Alliance 2003). Feedback loops (e.g., Figure 2-7) can also influence resilience whereby a structure of several loops can work in different ways to alter the system state after a perturbation (Meadows 2009). However, delayed, biased, scattered, or missing information due to barriers to information collection can also make desirably-influencing feedback loops malfunction or 'weaken' due to the social actors' inability to comprehend system changes (Meadows 2009). Recognizing the difficulties in the observation SES resilience, authors have asserted the importance of inferring resilience using indirect proxies (or "surrogates", as in (Bennett, Cumming & Peterson 2005; Carpenter, Westley & Turner 2005); Cumming et al. (2005).

2.2.7 A systems perspective for examining resilience

Resilience, as an emergent outcome of system change, cannot be assessed simply by examining the individual or the lower-level components of SES (Gunderson & Holling 2002). The observers' 'systems thinking' ability is seen as a requisite for assessing SES dynamics because "when considering systems of humans and nature [SES] it is important to consider the system as a whole." (Walker, Salt & Reid 2006, p. 38). In systems science, the term *systems thinking* (ST) itself refers to a specific discipline that has its own development of a body of literature (Jackson 2003). Understanding the structure, let alone the dynamics, of a system is a challenging task as most social actors are dealing with "… imperfect information about the state of the real world, confounding and ambiguous variables, poor scientific reasoning skills, defensive routines, and other barriers to effective group processes, implementation failure, and the misperceptions of feedback…" (Sterman 2000, p. 22). Yet, case studies of natural resource management have demonstrated that systems learning can be fortified through a multi-stakeholder participatory learning environment facilitating sharing of knowledge from different sources, embracing divergent perspectives, and conducting mental exercises to achieve a coherent view of the complex systemic problem (Bosch et al. 2007; Hovmand 2014; Nguyen et al. 2012). These social learning exercises are also essential in promoting *adaptive management* (more in Section 2.3), which is a leading indicator of the capacity of social actors to collaboratively learn and manage the resilience of the SES that influence (Armitage et al. 2009).

Scholars of modern approaches to ST share an interest in closely examining a number of fundamental system attributes (Reynolds & Holwell 2010). This includes, to analyse these components to varying degrees of: (1) the system components – or 'sub'-systems – that comprise (2) the system structure; (3) the system boundary that encapsulates the system that decided upon by the system examiner; and (4) the system 'behaviours' relative to the processes from (5) the direct and indirect relationships between the components, as well as (6) the input from and the output to the surroundings outside the system (Reynolds & Holwell 2010). The comprehension of these system properties has also been strongly reflected in several SES analytical objectives (i.e., Berkes, Colding and Folke (2003); Gunderson and Holling (2002)). Likewise, non-linear and dynamic system behaviours (e.g., SES as a CAS: Section 2.2.2) are at the analytical crux of a complex problem in social, economic, and ecosystem management (e.g., in the system dynamics modelling (Sterman 2000)).

2.2.8 The properties of SES dynamics as descriptors of resilience

Despite the epistemological overlaps, from reviews of natural resource management case studies and theoretical and empirical works, Walker et al. (2006) reveals three salient properties of

SES, including (1) resilience, alongside (2) adaptability, or “the capacity of the actors in the system to manage resilience”, and (3) transformability, or “the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system is untenable”. Likewise, these interpretive perspectives has been intrinsically embedded in studies using ST tools, such as systems dynamics modelling (e.g., resilience of management systems: forest resources: Suwarno et al. (2009), reef resources: Chang, Hong and Lee (2008), land use: Chen et al. (2004)) and soft systems methodology (e.g., adaptation to climate change Chen et al. (2004); Larsen et al. (2012)). Wright (2012) reviewed the relevance of multiple-systems-thinking-methods approaches to systems resilience enquiry.

In their summary of theoretical propositions, Walker et al. (2006) further assert that the aforementioned three properties determine two key SES dynamics, namely the ‘adaptive cycle’ and ‘panarchy’. The adaptive cycle is a “tool for thought” that views systems dynamics in four characteristic phases and two key transition periods (Box A, Figure 2-8). Each adaptive cycle is also connected to and influenced by other cycles creating a nested, non-hierarchical relationship that is described by systems theorists by the ‘panarchy’ structure (Gunderson & Holling 2002). In box A, Figure 2-8, as Gunderson and Holling (2002, p. 34) explain, the arrows indicate the flow of slow- (closely spaced) and fast-changing (long arrows) situation; the ‘potential’ y-axis indicates the level of information/materials/resources accumulated; the ‘connectedness’ x-axis refers to relationships between system variables. And the four phases of adaptive cycles are each assigned a symbol: (1) growth phase (r) : accumulation of resources, actors seizing opportunities, or successful events; (2) conservation phase (K) : sustained or slowing-down of growth, stability; (3) creative destruction (Ω) : represents the release or collapse of accumulated materials due to fragility frm over-accumulation; (4) reorganization phase (α) : represents a period of innovation and restructuring.

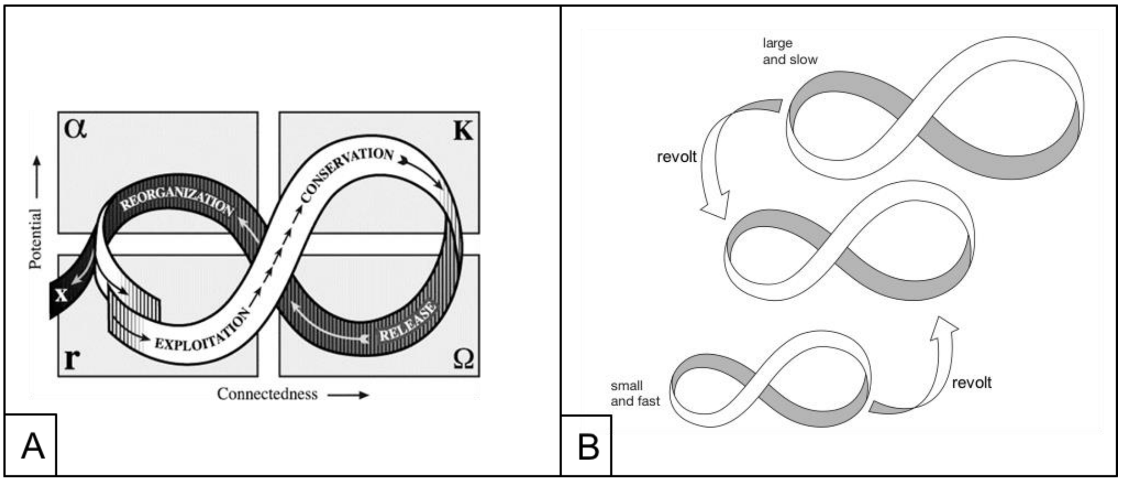

Figure 2-8. Diagrams illustrating the adaptive cycle (A, extracted from Gunderson and Holling (2002, p. 34)) and panarchy of a nested set of three adaptive cycles (B, extracted from Berkes (2015, p. 73)).

The panarchy structure (Box B, Figure 2-8) of adaptive cycles is developed from different systems structures, states, processes and dynamics of the (sub-) systems that interact within and across scales of different temporal and spatial domains (Gunderson & Holling 2002). The 'small and fast' loop at the bottom of Box B indicates a smaller scale or lower level of interaction in space and time, and the opposite condition is signified by the 'large and slow' loop. The downward-pointing arrow (labelled *remember*) indicates the potential accumulated and stored in the larger, slow levels that influences the reorganization (α) (e.g., fish seed spillovers accumulated by a coral reef refugia helps population recovery (McClanahan & Mangi 2000), decades of human interaction with nature promotes traditional rules in governing fishing activity (Cullen et al. 2002)). The upward arrow (labelleded *revolt*) indicates a situation in which fast and small events overwhelm slow and large events (e.g., rapid reproduction of small groups of introduced lionfish species triggered a shift in the composition of fish species in a reef region (Holdschlag & Ratter 2013), increasing loss of mangrove forest and leading to the shift in type of fishery activity (Armitage & Johnson 2006)).

2.3 The challenge of managing SES for resilience

2.3.1 Embracing uncertainty

Livelihoods, particularly those that are embedded in common-pool resource systems (i.e., fisheries), are a product of social interactions that determine the production as well as the sustainability of the ecosystem services, goods, and functions (Section 2.2.1). Yet, managing the resilience of a dynamic, complex, and adaptive SES with the aim of maintaining sustainable outcomes for both the well-being of nature and human remains a challenge for researchers and practitioners (Agrawal 2003; Folke et al. 2005; Kittinger et al. 2013).

It has been reported in scientific disciplines that the extreme complexity of many systems tends to limit our ability to obtain comprehensive information of the them (e.g., in social: Parsons (2005), economy: Wooldridge (2012), ecology: Jørgensen (2009), social-ecology: Ostrom (2009). This limitation is also compounded by the imprecise measurement of threshold variables in the system (Section 2.2.3). Uncertainty may also arise from the unpredictable and non-linear changes of key internal variables or external drivers of the system (e.g., from human behaviour: Anderies (2015), in ecosystem behaviour: Scheffer et al. (2001)). Predictions (as opposed to ‘projections’) or forecasts (as opposed to ‘possibilities’) of system changes that are contingent on these uncertain variables and drivers may also exhibit a vast probability of a diverse system outcome (Garland & Bradley 2015). If the probabilities or best estimates can provide only a narrow set of optimal decisions to be taken, relying strictly on these predictions or forecasts can lead to human actions that may not deliver the desired or predicted impact to future system changes (Polasky et al. 2011). This may also increase the possibility that the system changes faster than the human actors can re-measure variables or recalibrate the system of interest (e.g., underestimates of human populations: Mathers and Loncar (2006), climate: Rahmstorf, Foster and Cazenave (2012))

Proponents of both ecosystem and SES management recognise that past approaches to the management of dynamic systems have been focused on optimisation objectives such as maximising output for short time frame, leading to a narrow focus on individual variables (Fischer et al. 2009; Holling & Meffe 1996; Johnson, Williams & Nichols 2013; Peterson, Carpenter & Brock 2003). This type of management approach often overlooks key driving variables along with key social-ecological interactions, feedbacks, processes, and thresholds, which makes them insensitive to uncertainties of both the real-life process and the modelled system (Fischer et al. 2009; Holling & Meffe 1996; Johnson, Williams & Nichols 2013; Peterson, Carpenter & Brock 2003).

2.3.2 Operationalising the adaptive co-management of SES

In relation to this, studies of natural resource use and management have endorsed the concept of *adaptive co-management* (ACM) as a fundamental approach to managing an SES that is plagued by uncertainty (Berkes, F. 2009; Folke et al. 2005; Plummer 2009). Yet, co-management has its own theory development (i.e., Armitage, Berkes and Doubleday (2007)) similar to adaptive management (i.e., Williams and Brown (2014)), which originates from and shares the same principles as each of these concepts and the concept of resilience. Yet, scholars have delineated several key elements of the ACM process, including (1) a management environment containing a flexible institutional arrangement and regulations that allows (2) learning by treating management decisions, interventions, monitoring, and evaluation, as real-world experimentation; through a (3) collaborative mechanism that enables the sharing of resources, rights and responsibilities across multiple levels and scales (4) in an iterative manner (for in-depth discussions: Armitage et al. (2009); Berkes, F. (2009); Fabricius and Cundill (2014); Plummer (2009); Ruitenbeek and Cartier (2001)).

In terms of dealing with uncertainties, ACM explicitly encourages recognition of power relations among actors (e.g., in decision-making, authority and control, action, and knowledge) as well as trans-disciplinary measures that are critical to bridging organizations and knowledge systems (Armitage et al. 2009). Furthermore, it also encourages reducing uncertainty through the collaborative knowledge production in learning the SES properties (linkages, feedback, sub-systems, scale) (Fabricius & Cundill 2014). Accordingly, addressing problems related to an SES would require management decisions or interventions that are legitimate and corroborate a shared goal (Jentoft 2000). Legitimacy itself is also a requirement for both reflexive social learning and continuous knowledge exchange as mentioned earlier (Bos, Brown & Farrelly 2013).

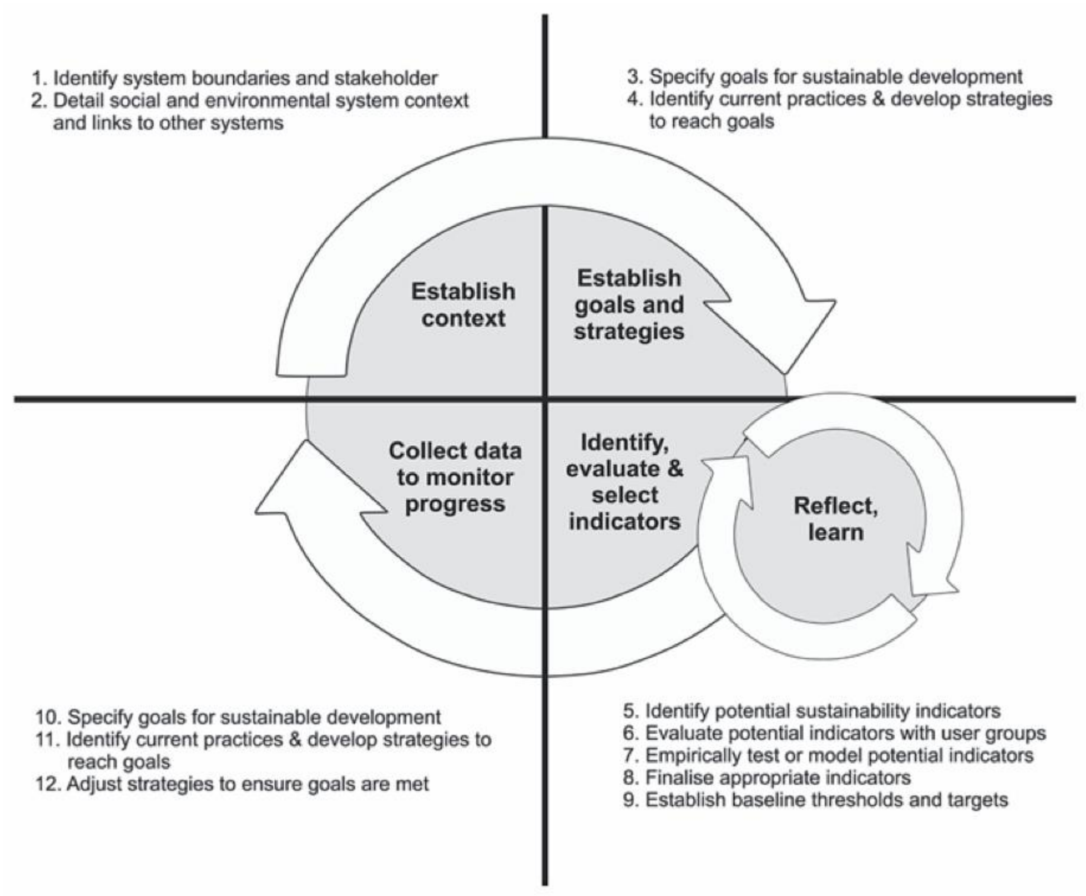

Figure 2-9. Diagram illustrating the ACM cycle (adapted from Reed, Fraser and Dougill (2006) and Stringer et al. (2006) *in* Fabricius and Currie (2015)) that constitutes a feedback mechanism between steps of structured decision-making (bigger loop) and steps of learning (smaller loop).

As the concept has increased in influence over the last five decades, a number of research and management frameworks have been developed to operationalise ACM in studies that aim to better comprehend uncertainty in decision-making and to improve natural resource management (Schreiber et al. 2004; Williams & Brown 2014). Yet, there are only a few successful examples of real-world implementation of the concept. In fisheries management, for example, of 30 case studies of attempts to implement ACM in developed regions, van Amstel et al. (2007) concluded that most have been failed "… in the sense that no experimental management program was ever implemented, and there have been serious problems with monitoring programs in the handful of cases where an experimental plan was implemented." Other case study reviews argue that ACM may not necessarily be a universal solution to management issues particularly in the context of systems that are lacking preconditions of ACM mechanism (Armitage et al. 2009; Fabricius & Currie 2015; Plummer 2009). In view of this challenge, Armitage et al. (2009) and Fabricius and Currie (2015) have encapsulated several key conditions that may operationalise ACM, which are:

1. Systems perspective where actors can see ACM as a complex adaptive process.
2. The ability of actors to set clear boundaries of the shared resource system.
3. Shared interests among identifiable stakeholders (i.e., a strong sense of place).
4. Management focuses on smaller-scale systems as opposed to larger regions or larger systems.
5. Clear property rights.
6. Management measures that are adaptable and accessible to the stakeholders.
7. Stakeholders' commitment to a long-term management process (i.e., allocation time).
8. Capacity to provide training and resources.
9. Presence of key actors, such as leaders and champions.
10. Interdependence, trust, and openness among actors representing diverse knowledge systems.
11. Social, governance, and policy environment (i.e., network, incentives, power balance) that support collaboration.

2.4 Synthesis: Implications of the literature review to the research

2.4.1 A conceptual framework for understanding the problem

To deduce and link theories explored in the previous sections, I have constructed a conceptual framework for examining the resilience of livelihood as a social-ecological system. Referring to the schematic in Figure 2-10, the segments (A, B, and C) and parts of the framework relate to the information presented in the sections of this chapter (shown inside parentheses) and, some information contained in Chapter 1 and 3. As shown in segment A in Figure 2-10, the framework begins with a hypothesis that the livelihood problem in Selayar, such as its dependence on the small-scale fishery, is related to a set of 'undesirable' social and ecological conditions that reveal the vulnerability of the livelihood. The problematic condition of the livelihood is also amplified by social or ecological influences originating from other systems at a larger or smaller scale.

In segment B (Figure 2-10), the framework views that a livelihood problem can be examined as a social-ecological system problem (i.e., blue boxes and arrow), which is based on the conceptual complementarity between the sustainable livelihood approach (SLA), and the social-ecological systems framework (SESF), which are presented earlier in Section 2.1.1 and illustrated in Figure 2-3. The boundary of the system under examination is defined by the social or ecological circumstances (e.g., trends or shocks), which can be under or beyond the control of the livelihood stakeholders, and which also define the vulnerability of their livelihood (i.e., red boxes and arrow). Using the SES point of view, the framework demonstrates that livelihood vulnerability can be contributed to by both endogenously and exogenously controlling variables which are interacting in a complex manner and involving feedback mechanism (i.e., boxes inside 'Livelihood as a social-ecological system'). The feedbacks can include both those that are maintaining and diminishing the problematic livelihood state over time and – together with social and ecological thresholds or 'tipping points' – they determine the irreversibility of the trajectory of the livelihood state changes (i.e., boxes inside 'Livelihood as a social-ecological system'). Still on segment B (Figure 2-10), the framework shows that the feedback mechanisms within the SES of interest are also responsible for generating the non-linear and dynamic changes of the livelihood system, which may include problematic state changes that are locked in a 'path' and difficult for the stakeholder to alter or avoid (i.e., green boxes and arrow). In addition to the aforementioned assessment of SES complexity, the framework suggests that the system changes over time (i.e., the system's dynamics) can illustrate the adaptive property of the system, which can provide insights into, for example, how the problematic livelihood changes are developed and how the system responds (i.e., 'self-organises') to the introduced policies or scenarios.

Referring to segment C (Figure 2-10), the framework shows that a systems perspective is imperative to explore the aforementioned aspects in segment B, which has brought about a research approach that employs the system thinking and modelling framework (Chapter 3). The expected outcome of the systems inquiry is that it will offer insights (i.e., brown box) for examining the resilience of the SES in a data-poor region such as Selayar. The methodology involved in capturing mental, written, and numerical data and materials generated from both primary (from several assessments: problem scoping, group model building, an interview-based survey in Section 3.6.1, 3.6.2, and 3.6.4; respectively) and secondary sources (from pre-existing data, in Section 3.6.6). The inquiry for this information was guided by sets of key questions that outline the main assessments in this research (see next sections). The addressing of these questions and the examination of resilience (i.e., brown box) were then achieved by triangulating the assessment outputs that comprise both normative (i.e., defined by the stakeholders using problem scoping, group model building, supplementary interview: Section 3.6.1 3.6.2, 3.6.4) as well as empirical (i.e., the researchers' analysis: using systems dynamics modelling, simulation-aided evaluation/analysis, reanalysis of questionnaire-based survey dataset: Section 3.6.4, 3.6.5, 3.6.6).

Several sets of key questions were raised based on this framework, which was mainly derived from the many aspects in the framework that have not yet been explored in Selayar. Three main assessments were conducted to address the questions, which link the overarching objective and method of research (Section 1.3). The key questions and the associated main assessments are presented in the next sections.

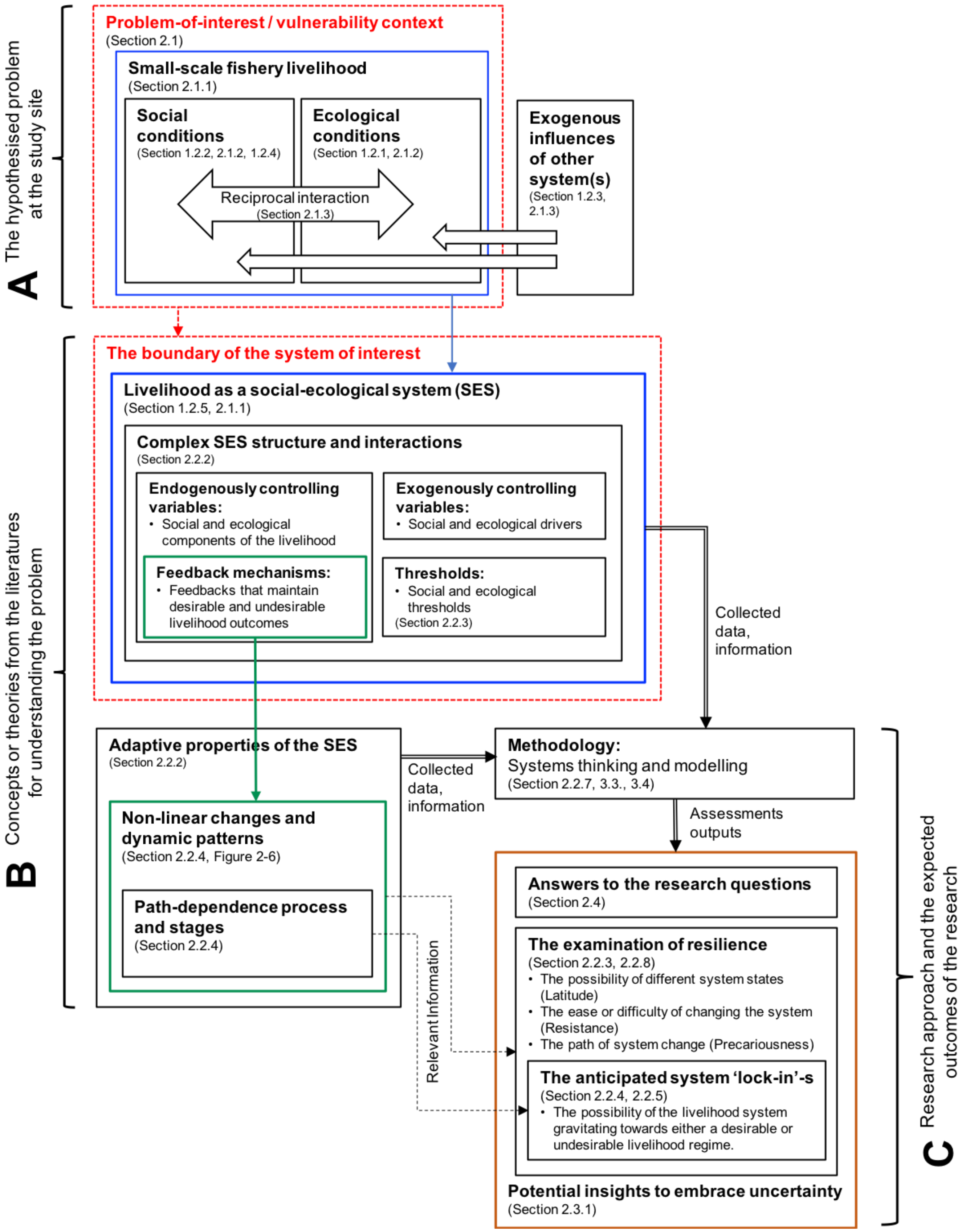

Figure 2-10. A schematic describing the theories and concepts (presented in the earlier sections) for examining the resilience of livelihood as a social-ecological system.

2.4.2 Main Assessment 1

This literature review has asserted that a holistic approach and analysis is necessary to develop the understanding of livelihood-related problems such as those related with the small-scale fishing communities in Indonesia and particularly in a data-poor region such as in the Selayar island (i.e., Section 2.2. Besides limited information, the vulnerability of the livelihood of the Selayar communities is likely an outcome of the complexity of both human and environmental dimensions (i.e., Section 2.1, 2.2) that, however, were minimally understood at the time of the study. The classification of livelihood as a social-ecological system (SES) is therefore pivotal to allow, for example, the identification of the components and its interactions as much as possible; and to identify knowledge gaps particularly on social-ecological pathways that maintain the mismatch between the utilisation of natural resources and the preservation/management of those resources. Therefore, several key questions were raised, which are:

1. What are the current livelihood systems and marine ecosystems occurring with the study area and the problems experienced by the associated communities? (Ch. 4).
2. What are the socio-ecological system components within the study area and the interactions between these components? (Ch. 4 and 5).
3. How do interactions between the socio-ecological system components cause mismatches between local livelihood activity and natural resource management in the study area? (Ch. 5).

Accordingly, these questions were addressed through Main Assessment 1, which is to conceptually model interactions within the social-ecological systems that drive livelihoods operating in Selayar Islands Regency, South Sulawesi Indonesia.

2.4.3 Main Assessment 2

Furthermore, path-dependence processes have historically contributed to the persistence of some problems that commonly exist in SES including in coastal livelihoods in the developing region (i.e., the ‘trap’: Section 2.1.3). Undesirable conditions with a ‘trap’ attribute have been documented in Indonesia, such as the social changes that maintain livelihoods in a poverty state and environmental changes that sustain a low-quality or low-abundant economically important fishery resource (e.g., Section 1.2). However, at the time of the study, evidence of the social-ecological trap (SET) much less of its causal mechanisms (i.e., feedback interactions of variables: Section 2.2.4) was not yet fully explored in the Indonesian region especially for areas of national priority for conservation and the fishery-dependent economy such as in Selayar. Hence, this review also calls into the key questions of:

1. What are the flows of material or information within the local socio-ecological system and how do these flows influence system dynamics? (Ch. 6).
2. What are the key ecological, social and economic drivers that influence material and information flows and how do these drivers influence system dynamics particularly that are undesirable? (Ch. 6).

These research questions were addressed using Main Assessment 2, which is to quantitatively model the feedback interactions between key socio-ecological system components influencing the behaviour of local livelihood systems. Main Assessment 2 is expected encompass the uncertainty of the examined SES (i.e., Section 2.3.1) by using the systems dynamics modelling approach (Section 3.3, 3.4) to simulate the trajectories of the key social, economic, or ecological variables (i.e., multiple dynamic equilibria: Section 2.2.4) particularly of those that can render problematic system state that may be difficult to reverse (i.e., the lock-in: Section 2.2.5).

2.4.4 Main Assessment 3

Furthermore, this research is also expected to take part in improving the adaptability of the SES stakeholders in the study site, at the least, by providing support in the learning to anticipate the changes of the system (i.e., operationalising the ACM: Section 2.3.2). As this research is part of a problem-solving effort (i.e., the CCRES project: Section 1.1), this research acknowledges that the introduction of an intervention (i.e., policies) to the problem can render outcomes that can be desirable (i.e., promote system trajectory that ultimately avoids the lock-ins: Section 2.2.4) and undesirable, which can be expected (thus, intended) or not expected (thus, unintended) by the SES stakeholders (i.e., the emergent property: Section 2.2.2). At the same time, in modelling the resilience of an SES, it is unavoidable that only a boundary of the SES that an investigator can examine (Section 2.2.7) due to, for example, the limited set of information (i.e., Section 2.2.6) that informs the state variables (Section 2.2.4) and the uncontrollable external drivers of the system (Section 2.3.1). Accordingly, the reasons raise the last four key questions, which are:

1. What characteristics of the socio-ecological system make them undesirably or desirably resilient? (Ch. 5 & 6).
2. How will the proposed intervention(s), undesirably or desirably, modify the resilience of the system? (Ch. 7).
3. How resilient will the systems to the potential ecological/social disturbances that the system can experience in future? (Ch. 7).

These questions were addressed through Main Assessment 3, which is to conduct a simulation-aided evaluation of the alternative livelihood configuration to future uncertainty. In this assessment, alternative configuration refers to the application of policy interventions that can produce the system outcomes that could be desirable (e.g., trends that avoids lock-in towards a trap) and undesirable (e.g., trade-offs due to policy consequences that is unexpected in particular). While future uncertainty refers to the consideration possibilities of uncontrolled or externally imposed influences on the system.

Chapter 3 Research approach and methodology

3.1 Research design in general

Owing to the data-poor situation in Selayar (i.e., insufficient information to describe the system of interest: Section 2.4.2), a 'case study' approach was used in the inquiry. And I was also dealing with some contemporary events over which I had no control (Yin 2009). In a case study, "… the researcher develops an in-depth analysis of a case … event, activity, process, or one or more individuals. Cases are bounded by time and activity, and researchers collect detailed information using a variety of data collection procedures over a sustained period of time" (Creswell 2014, p. 14)

Given the "what" and "how" questions and the nature of the problem to be investigated, I took both an 'exploratory' and 'explanatory' approach to this research. I chose the exploratory method as it was able to deal with a problem that was not yet clearly defined at the beginning of the study, and the explanatory method was useful since there are little-known descriptions of characteristics of the problem (Yin 2009, Chapter 2). The case study employed a 'mixed-method' research design as I was expecting to encounter practical difficulties (i.e., in data collection, problem analysis) when examining the problem. The study also involves a diverse set of actors, data, and material and influences a range of actions or processes (Creswell 2014, p. 14). This design applies both qualitative and quantitative methods to capture and triangulate a "spectrum" of 'hard' (e.g., statistical information, un-/controlled experiments, biological and physical processes) as well as 'soft' (e.g., other case studies, expert judgment, stakeholder knowledge, personal intuition) information sources to understand the problem (Ford 2010, p. 153).

As the real-world problem was not directly controllable, manipulable, or alterable, I constructed my understanding by relying on the 'non-experimental' elements of this mixed-method design, such as interpretation, observation, and interactions (Creswell 2014, p. 12). Furthermore, 'quasi-experimental' procedures were also used to test experimental treatment conditions using a representation of the real-world problem (or, a modelled problem) (Yin 2009). This approach enabled me to engage in 'learning by experimentation' to examine the simulated problem under controlled conditions; this allows problem manipulation using simulated treatments or interventions, such as changing an independent variable and observing its effect on the dependent variable (Ford 2010, p. 5). Furthermore, methods were applied in a 'participatory' process, whereby information from actors/stakeholders was acquired to build a commonly accepted representation of the problem with which they are associated (Hovmand 2014, p. 6). This process was considered a critical part of establishing a degree of relevance, validity, or feasibility of a virtual analysis of the problem to the stakeholders in solving their real-world problem (Sterman 2000, Chapter 2).

3.2 A conceptual framework for assessing the problem

A conceptual framework deduced from the literature review is explained earlier in Chapter 2 in Section 2.4.1 and depicted in Figure 2-10.

3.3 Methodological approaches

In an extensive review of the history of systems thinking and the development of the concepts for solving real-world problems (Jackson 2003) reveals that applying systems thinking may require combining different systems methodologies, models, and methods. The author identifies a "system of systems methodology" that emerged during the development of diverse case studies dealing with diverse systems (e.g., simple and complex) and their associated actors (e.g., individuals, communities) (Jackson 2003, p. 217). Given the traits of the ten established systems methodologies, the author argues that one should use a methodology based on the "purposefulness" of the enquiry (Jackson 2003, p. 24) and identifies four purpose categories: (1) "improve goal seeking and viability", (2) "explore purposes", (3) "ensure fairness", and (4) "promote diversity".

This typology warranted research into a number of methodological approaches, including:

- Soft systems methodology (i.e., purpose category 1) – because answering the 'what' questions (e.g., question 1 to 3 of Main Assessment 1: Section 2.4) critically requires the researcher, for example, to learn from the problem owners and, therefore, deal with various knowledge systems in order to elicit the problem (Checkland & Poulter 2006);
- Hard systems thinking approach (i.e., purpose category 2) – since the role of a 'systems person' (i.e., the researcher) requires an understanding of the dynamic properties (i.e., path-dependency, Section 2.2.4) of the problematic system (Jackson 2003, p. 47); which also relates to
- Systems dynamics methodology (i.e., purpose category 1) – to establish the boundary of the system of interest, assess the dynamic behaviours of the problem, identify network of feedback loops (Section 2.2.1; and question 1 and 2 of Main Assessment 1: Section 2.4), determine the stock and flow of materials/information (Questions of Main Assessment 2: Section 2.4), and provide insights to the problem owners of the actual and alternative system condition (Question 3 and 4 of Main Assessment 3).

3.4 Methodological framework

A sequential exploratory methodological design was used in this research. The design involves a research procedure that begins with either a stage of quantitative or qualitative data collection and analysis, the output from which will be used in the next stage of enquiry; and, later, these results feed into an interpretation stage (Creswell & Plano Clark 2011, p. 16) (Figure 3-1).

The procedure builds on the framework of systems thinking and modelling (STM) intervention process by (Cavana & Maani 2000); Maani and Cavana (2007). The STM process comprises several phases (Figure 3-2) each of which involve a number of analytical steps that utilise one or several methods (Table 3-1). As indicated in Table 3-1, not all phases or steps in the STM were included in this study due to considerations related to the scope of research questions, resource and time limitation of the PhD study, and therefore, the practicality of the methodological approaches. Although the structure of the methods is sequential, part of the learning process was iterative, whereby a particular step might be revisited by the modeller or problem owners as part of developing their understanding (Figure 3-3).

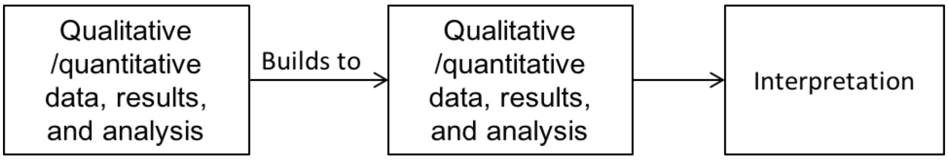

Figure 3-1. A schematic describing the stages in sequential exploratory research adapted from Creswell and Plano Clark (2011).

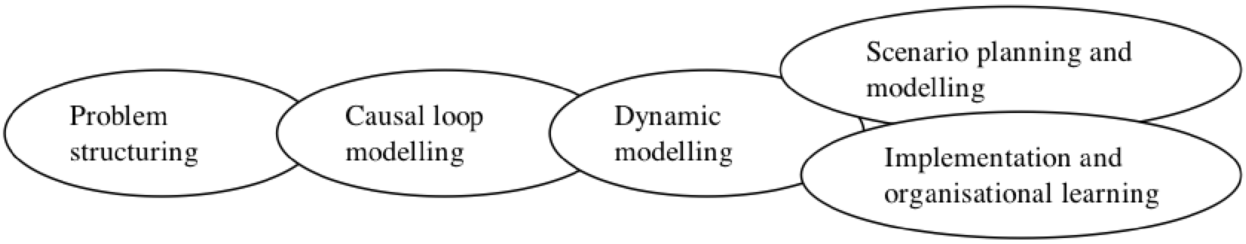

Figure 3-2. The five phases of the STM of Cavana and Maani (2000, p. 5) adopted in this research excluding the implementation and organisational learning phase.

Table 3-1. Steps of the STM process Cavana and Maani (2000, p. 5) applied in this study (√) corresponding to the sequential and iterative process described in Figure 3-2. Research approach: SSM (Soft systems methodology), HSA (Hard systems thinking approach), SDM (Systems dynamics methodology). Activity: PS (Problem scoping with stakeholder), LR (Literature review), SI (Secondary information/data collation & analysis), SCS (Interview- or questionnaire-based social survey), SFG (Stakeholder focus group discussions), QLM (Qualitative modelling assessment), QNM (Quantitative modelling assessment).

STM phase	No.	Step description √ = Included in this research		Method (Research approach)	Related activity in this research (Section/chapter number)
1. Problem identification	1	Identify problems or issues of concern to management	√	• Rich picture development (SSM) • Stakeholder identification (SSM) • Problem prioritization (SSM)	PS (3.6.1)

STM phase	No.	Step description √ = Included in this research		Method (Research approach)	Related activity in this research (Section/chapter number)
	2	Collect preliminary information and data	√	Secondary information & data mining (HSA)	SI (3.6.6) LR (Chapter 2)
2. Causal loop modelling	1	Identify the main variables	√	• Group model building with stakeholder (SSM) • Causal loop modelling & analysis (SDM)	SFG (3.6.2) QLM (3.6.3)
	2	Develop causal loop diagrams (influence diagrams)	√	• Group model building with stakeholder (SSM) • Causal loop modelling & analysis (SDM) • Primary & secondary information/data mining (HSA, SDM)	SFG (3.6.2) QLM (3.6.3) SCS (3.6.4)
	3	Identify feedback loops and conceptual loop behaviour	√		
	4	Identify systems archetypes	√		
	5	Prepare hypothetical / conceptual behaviour-over-time graphs (reference modes)	√		
	6	Identify potential leverage points	√		
	7	Develop potential intervention strategies	√		
3. Dynamic modelling	1	Develop a map or rich picture of the system	√	Stock-and-flow diagramming (SDM)	QNM (3.6.5)
	2	Define variable types and construct stock-and-flow diagrams	√	Primary & secondary information/data mining (HSA, SDM)	SI (3.6.6) SCS (3.6.4)
	3	Collect detailed information and data for model parameterisation	√	Dynamic modelling in the Stella® Architect software (SDM)	QNM (3.6.5)
	4	Develop a simulation model to simulate steady-state / stability conditions	√		
	5	Perform model tests/checks of: - Structure verification, boundary adequacy - Unit consistency - Mass-balance - Extreme conditions - Model sensitivity - Model uncertainty	√		
	6	Reproduce reference modes (base case)	√		
4. Planning & modelling of policies/strategies under scenarios	1	Design policies based on the potential key drivers of change (leverage points)	√	Policy analysis using dynamic model simulation (SDM)	QNM (3.6.5)
	2	Develop & test strategies based on keynote uncertainties	√		
	3	Plan general scope of scenarios and simulate policies under the scenario	√		
	4	Construct forced & learning scenarios			
	5	Simulate scenario(s) with the model	√		
	6	Evaluate the robustness of the policies and strategies	√		
5. Implementation &	1	Prepare a report and presentation to management			
	2	Communicate results and insights of proposed intervention to stakeholders			

STM phase	No.	Step description √ = Included in this research		Method (Research approach)	Related activity in this research (Section/chapter number)
	3	Develop a micro-world and learning lab based on the simulation model			
	4	Use a learning lab to examine mental models and facilitate learning in the organisation			

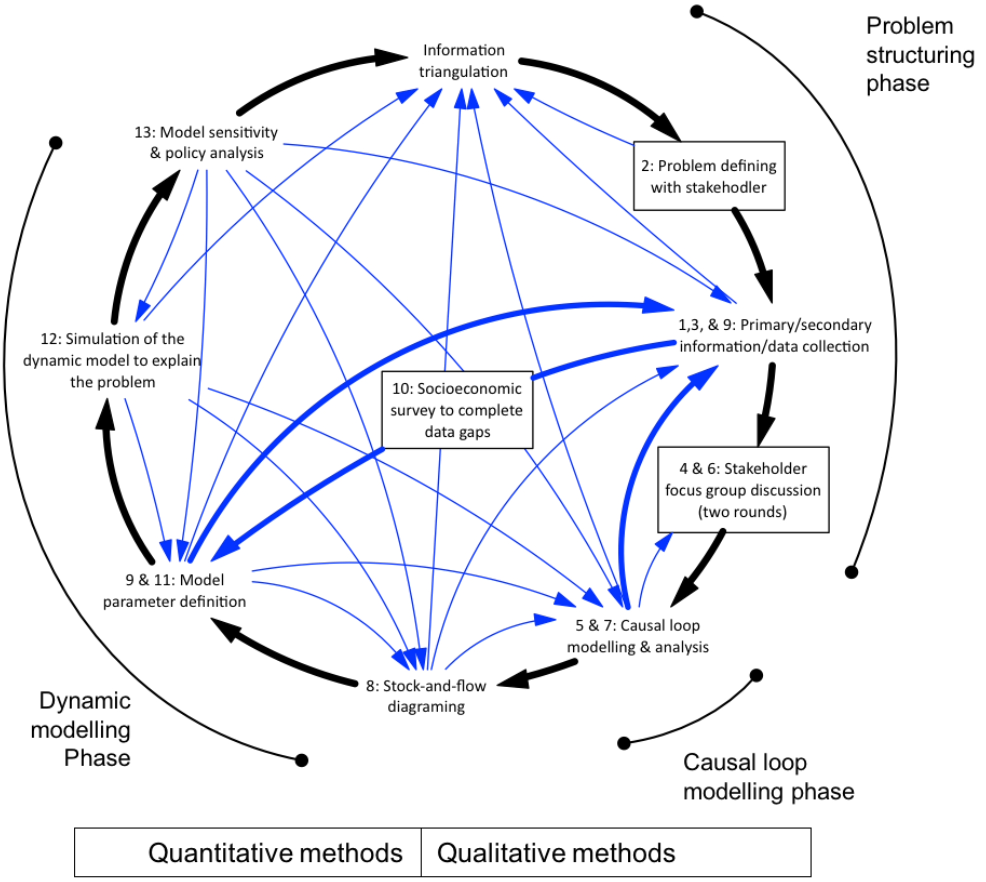

Figure 3-3. A framework (modified from Ford (2010, p. 161) showing the sequence (marked by the numbers, black arrows) as well as iteration (marked with blue arrows) of the methodology component in Table 3-1. Revisiting a step was unavoidable as this research followed the “simulate early and often” strategy referring to the work of Beall (2007) in Ford (2010, p. 160), whereby advancement to the next step of will be made to be possible although a step or procedure is not yet ‘complete’.

3.5 The research team and local collaborator

For a number of the main activities, I worked with the Systems Analysis Team of the CCRES project (hereafter referred to as ‘the team’), and a person from the area was employed as a local collaborator. The contributions of other team members are described in the preliminary pages. At the time of the study, the team was composed of:

- Three Indonesian experts, including Dr Novie Andri Setianto (NS) – a systems modeller from Jenderal Soedirman University with expertise in Indonesian agriculture and small-holder farming, Suryo Kusumo, M.Sc. (SK) – a systems modeller from the Bogor Institute of Agriculture (IPB) with expertise in coastal and marine resource management, Dr Luky Adrianto (LK) – a systems modeller with expertise in coastal and marine resource economics also based in IPB;

- Two Australian experts, namely Dr Carl Smith (CS), a senior lecturer and systems thinking and dynamics expert from The University of Queensland (UQ), and Dr Russell Richards (RR) a postdoctoral researcher from UQ who works on modelling applications for coastal and marine systems research.

To assist in my research activities, the team appointed Mr Andi Penrang (hereafter referred to as Pak Andi) as local collaborator, owing to credentials that the team identified during personal communications (on 10 February 2015, during an initial stakeholder engagement visit, and 8 August 2015, before the problem scoping days). The role of local collaborator included the following responsibilities:

1. Provide additional practical advice and technical support, particularly to ensure socio-cultural suitability of the fieldwork activities;
2. Ensure that the team operated neutrally (to identify and control bias) during the participatory planning and executing activities, which were undertaken in a diverse community (e.g., rural communities, government staff, cultural leaders, business representatives); and
3. Provide communication support, including Indonesian-Selayarese translation.

Pak Andi is a Selayar native who at the time of this study was a member of the Department of Fisheries and Marine office and community-appointed head of a *Dusun* (sub-village). He has previously been involved in local coastal community development and research projects run by Indonesian government agencies (e.g., the COREMAP), as well as academic (e.g., Hasanuddin University) and non-governmental (e.g., JICA, Grameen Bank, the World Bank) organisations. He has undertaken extensive training (and trained other instructors) for community outreach duties, such as establishing and organising groups, facilitating community-based activities, and assisting social surveys in Selayar. Having thus established his reputation, Pak Andi was able to set up a vast local network as well as a communication channel with fishing communities, coastal village leaders, and community groups including those engaging in illegal fishing activities. And during his master’s degree candidature at a local university, he gained academic experience in environmental knowledge and research ethics.

3.6 Main activities

I conducted six main activities with the research team to implement the methodological framework introduced in Section 3.4, which includes problem scoping (Activity 1), problem mapping (Activity 2), causal modelling (Activity 3), a supplementary interview (Activity 4), dynamic modelling (Activity 5), and secondary information collation (Activity 6). Each of these activities is elaborated in six subsections (3.6.1, 3.6.2, 3.6.3, 3.6.4, 3.6.5, and 3.6.6). Activities 1, 2, and 4 involved the participation of the fisher-dominated village residents on Selayar Island (Village locations map: Figure 3-4, Summary of schedules and number of participants: Table 3-3). The activity number does not indicate sequence. The activities were conducted in the following order:

1. Activity 1
2. Activity 2 (Round One)
3. Activity 3
4. Activity 2 (Round Two)
5. Activity 3
6. Activity 4
7. Activity 5

Activity 6 commenced after the fourth sequence and was held simultaneously with the other activities. In general, these activities were conducted in the identified fisher-dominated villages (about village identification and selection: Section 3.6.1.2) on Selayar and Gusung Pasi Island (Figure 3-4). Participant criteria were determined for each of the participatory activities (i.e., Activity 1 and 2: Section 3.6.1.3, 3.6.2.4; Activity 4: Section 5.2.2.4). However, the number of villages represented, and the number of people involved in each of the participatory activities (i.e., Activities 1, 2, and 4) varied, as summarised in Table 3-3. There was no minimum number of village population samples determined in the participatory activities since the activities implemented the soft systems methodology (Section 3.3), a qualitative method of inquiry that partly lay the foundation of the STM framework adopted in this research (Section 3.4, Cavana and Maani (2000, p. 5)). The links between these activities and the key questions and conceptual framework are summarised in Table 3-2.

Table 3-2. The conceptual relationship between key information obtained from each of the six activities (Section 3.6.1 to 3.6.2) and the main assessments and key questions (Section 2.4.2 to 2.4.4) and the main aspects of the conceptual framework (Section 2.4.1)

No.	Research activity	Related results chapters (C), main assessment (A), and key question (Q)	Key information obtained from the activity	Main aspects of the conceptual framework related to the key information
1	Problem scoping	Chapter 4 A1 (Q1, Q2)	• The community-defined topic of the livelihood problem. • The stakeholders associated with the livelihood problem.	• The problem-of-interest (the 'vulnerability context').
2	Problem mapping	Chapter 5 A1 (Q2, Q3) A3 (Q1)	• The variables related to livelihood activities, resource, pressures, decisions. • The interaction between the variables and its polarity	• The boundary of the system of interest. • The conceptual depiction of the complex structure and interactions of the SES. • The identification of the endogenous and exogenous variables influencing the livelihood. • Feedback mechanisms
3	Causal modelling	Chapter 5 A1 (Q2, Q3) A3 (Q1)	• The feedback loops originating from the interactions of variables. • The identified state variables, and the exogenous/driver/threshold variables. • The conceptual behaviour of the livelihood state variables over time.	
4	Supplementary interview	Chapter 5 A1 (Q2, Q3) A3 (Q1)	• Stakeholder-clarified variables and interactions in the causal model.	
5	Dynamic modelling	Chapter 6,7 A2 (Q1, Q2) A3 (Q2, Q3)	• The projected dynamics of the inventory of the materials/information, and its rate of change, of the livelihood system over a simulated time. • The livelihood dynamics that are relatable to the problematic trends perceived by the community. • The indication of a path-dependent trajectory of change of the livelihood state variables. • The livelihood dynamics – of both that are desirable and undesirable – that are produced	• Non-linear changes and dynamic patterns resulting from the feedback relationships between variables. • Path-dependence process and stages. • The examination of resilience. • The anticipate system 'lock-in'.

No.	Research activity	Related results chapters (C), main assessment (A), and key question (Q)	Key information obtained from the activity	Main aspects of the conceptual framework related to the key information
			when policies and scenarios are applied.	
6	Secondary-sourced information collation	A1 (Q2, Q3) A2 (Q1, Q2) A3 (Q1 -3)	• The information from secondary sources that justifies the defined variables, interactions, and polarity in the causal model; and the assumptions in the stock-and-flow model parameters.	• The social and ecological variables, interactions, and thresholds defining the SES/livelihood.

Table 3-3. Operational relationships between the participatory activities. The summary of the dates and the number of participants of the focus group discussions (FGD) in Activity 1 and Activity 2, and the dates and the number of respondents (i.e., interviews) in Activity 4.

No.	District name	Village name	Activity 1: Problem scoping FGD		Activity 2: Problem mapping FGD (Round One)		Activity 3: Problem mapping FGD (Round Two)		Activity 4: Supplementary interview	
			FGD date	No. of participants	FGD date (Group 1, Group 2)	No. of participants	FGD date (Group 1, Group 2)	No. of participants	FGD date	No. of respondents
1	Bontomatene	Bungaiya	10/08/2015	16	1/10/2015, 2/10/2015	29	26/01/2016, 27/01/2016	29	20/09/2016	3
2	Bontomatene	Barat Lambongan	10/08/2015	9	11/10/2015, 12/10/2015	29	24/01/2016, 25/01/2016	25	19/09/2016	4
3	Buki	Mekar Indah	11/08/2015	10					21/09/2016	3
4	Bontomanai	Barugaiya	13/08/2015	15	17/10/2015, 19/10/2015	31	28/02/2016, 26/02/2016	33	22/09/2016	2
5	Bontomanai	Parak	12/08/2015	12					23/09/2016	2
6	Benteng	Benteng Utara	10/08/2015	13	20/10/2015, 21/10/2015	29	27/02/2016, 26/02/2016	46	24/09/2016	1
7	Bontoharu	Bontolebang	13/08/2015	16						
8	Bontoharu	Kahu-kahu	12/08/2015	10	27/09/2015, 28/09/2015	36	24/01/2016, 24/01/2016	28		
9	Bontoharu	Bontoborusu	13/08/2015	10	29/09/2015, 30/09/2015	29	2/02/2016, 25/02/2016	26	25/09/2016	3
10	Bontoharu	Bontosunggu	11/08/2015	14	15/10/2015 (Group 1 only)	17	23/02/2016 (Group 1 only)	15		
11	Bontosikuyu	Harapan-Dodaiya	11/08/2015	15						
12	Bontosikuyu	Patikarya	11/08/2015	15	13/10/2015, 14/10/2015	43	28/01/2016, 29/01/2016	28		
		Total:	12 FGDs	155 people	15 FGDs	243 people	15 FGDs	230 people		18 respondents

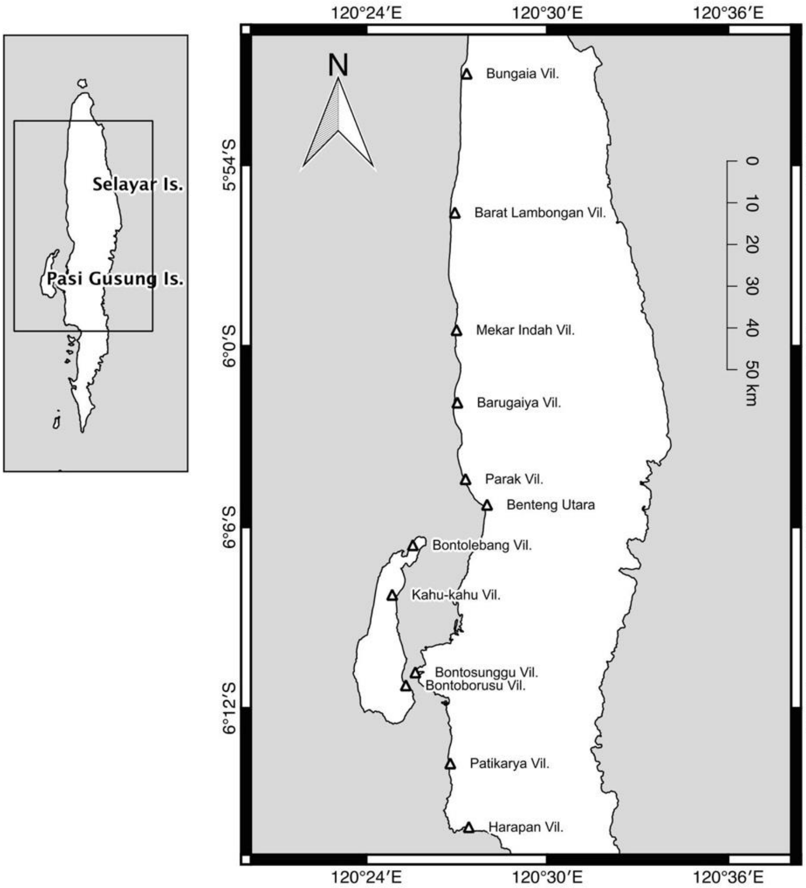

Figure 3-4. Map showing the locations of 'fishing villages' on Selayar and Gusung Pasi Islands where problem scoping FGDs were conducted.

3.6.1 Activity 1: Problem scoping

3.6.1.1 Problem scoping objectives and methods

The problem scoping activity mainly involved focus group discussions (FGDs) (Krueger & Casey 2009) facilitated by the Indonesian team members (Section 3.5) using discussion scripts (Appendix 3). Each FGD was designed to achieve the following objectives:

1. To identify problems, which was achieved by guiding the FGD participants to build rich pictures (Checkland 2000). Rich picture building is a soft systems method that can help to identify problems that a stakeholder wants to address by describing an "… unstructured description of the situation where the issue lies … to reflect as much going on as possible without privileging, predetermining, or presuming a particular point of view" (Williams & Hummelbrunner 2007, p. 244). Participants were asked to draw a map of their village, identifying the activities that they do, the resources they use, and any trends that they had noticed in these activities and resources over the past 5 to 10 years. This helped us to identify problematic trends in activities and resources (hence, the first result).

2. To prioritise the identified problem, which was achieved by guiding FGD participants to develop a list containing three to five of selected livelihood problems in order of importance (hence, the second result). Another purpose of the problem listing was to capture the degree of the ownership of the problems by allowing a decision-making role in the research process (Checkland 1981, p. 4; 2000). This would increase the team's confidence in choosing the topic problem(s) (problems of interest) to be investigated.
3. To obtain stakeholder information related to the problem, which was done by guiding FGD participants to complete a bullseye diagram that identified direct and indirect stakeholders they perceived as affecting and being affected by the problem. The stakeholder analysis was used later mainly to determine groupings of participants invited in the problem mapping FGDs in Activity 2 (Section 3.6.2); (hence, the third result).

3.6.1.2 Location selection of problem scoping FGDs

The FGD sites for all of the main activities conducted during this research were chosen based on villages (or, desa), which are the lowest administrative divisions in Indonesia. The desa is also considered as an existing settlement boundary containing an aggregate of communities that share a particular characteristic. All dwellings on Selayar are part of the administrative divisions. Ahead of the FGD days, with the help of the team and the local collaborators (Section 3.5) I determined the FGD locations based on villages where more than 50% of residents work in fishing or fish supply chain-related occupations (e.g., fish trader, collector). The villages meeting this demographic criterion were identified using existing maps and village demographic information gathered from the local administrative offices. Thirteen villages under the criterion were listed. However, one of these villages (Appatanah),located at the southern tip of Selayar Island was excluded due to limited time and access constraints during the fieldwork. One problem-scoping FGD was conducted for each of the twelve fisher-dominated villages (a total of ten FGDs) that span all six districts of the island (Schedule and village locations: Table 3-3, Figure 3-4).

3.6.1.3 Participant recruitment criteria for the problem scoping

The identification, selection, and invitation of the FGD participants in all main activities were carried out by the local collaborators (Section 3.5). To execute this, the collaborators primarily worked with the head of the village and/or community group coordinators (e.g., fishermen, household business, and/or women's groups). The delegation was mainly due to none of the Indonesian team members being familiar with Selayar's local language or customs. The collaborators' socio-cultural capacity (i.e., understanding of local norms and taboos, use of local language, presence of a native person) would bring effective communication of the team with the local people.

The team prepared recruitment documents (Appendix 2) to minimise selection bias on the behalf of collaboratorss and to comply with UQ's ethical guidelines for research involving human subjects (Appendix 1). These materials were used by the collaborators to maintain consistency when inviting and obtaining consent (written or verbal) from participants in Selayar. The documents consist of:

1. A participant information kit that describing such details as the project background, participant selection criteria, focus group procedures, and contact details.
2. Both a digital and hard copy of the consent form in Bahasa Indonesian.

3.6.1.4 Data outputs and method of analysis in the problem scoping

Each problem-scoping FGD generated data outputs consisting of:

- Rich pictures that depict livelihood conditions in the village.
- A list of prioritised livelihood problems.
- A bullseye diagram of problem stakeholders.
- Digital photos and audio recordings of the FGD activities.
- Written notes.
- A participant list from each FGD.

In the computer lab, information related to livelihood systems components (i.e., the SES variables, Figure 2-10) were extracted from these materials and tabulated using Excel™ software, which was thematically organised according to (1) the primary and non-primary livelihood activities, (2) the key natural resources associated to the livelihood activities, (3) the perceived past/recent trends of the resource and the livelihood activities, (4) the main livelihood problems associated to the resources and activities, and (5) the key stakeholders associated with the problems. The first and second themes were defined to capture the social and ecological components of the livelihood (i.e., the livelihood assets and policies, institutions, and process, Box B, Figure 2-3), and the indications of problematic livelihood state or past changes (i.e., the vulnerability context and livelihood outcome, Box B, Figure 2-3) using the third and fourth theme. During the extraction, information from the elements of the output materials (i.e., of both text and pictures) that had a similar meaning and were repeated were merged and rephrased. Information that was relevant to the themes was then compiled in several tables (Table 4-2, Table 4-3, Table 4-4). In relation to the objective of the problem scoping (Section 3.6.1.1), the tabulated information was later used by the team to:

1. Define the problem(s)-of-interest (or, topic problem) to be investigated later in the next assessment (Section 3.6.2).

2. Determine the stakeholder groupings of the participants who would be invited to the following problem mapping activity (Section 3.6.2).

3.6.2 Activity 2: Problem mapping (Group model-building with stakeholders)

3.6.2.1 Problem mapping methods and objectives

A number of FGDs were held to facilitate socio-ecological systems mapping about the topic problem (Section 3.6.1.4) with community members of Selayar and Gusung Pasi Islands (for the problem-mapping schedule, see: Section 5.1.1.1). In each FGD, a script was used by the Indonesian team members to facilitate participants in a group model-building (GMB) activity (Hovmand 2014) (Appendix 4, Appendix 5). The purpose of GMB is to integrate knowledge from multiple sources and people and to develop a shared understanding of how the problem arose and how it might be solved (a common dynamic hypothesis) (Hovmand 2014). GMB allows for an integrated approach incorporating 'soft' and 'hard' systems thinking approaches (Jackson 2003), in consideration of unstructured subjective elements - such as multiple perceptions, different beliefs and values, issues of politics and power related to the problem owners (e.g., participants from Selayar and Gusung Pasi Island) in the problem-modelling procedure (Hovmand 2014).

The objectives of the GMB in the FGDs were:

1. To facilitate participants in developing rich pictures that identify the underlying system structures and feedback loops that influence the problem of interest or the topic problem. This was the objective of the first round of problem-mapping FGDs (schedule: Table 5-1), and the GMB was guided using a script as described in Appendix 4.
2. To facilitate participants in reviewing the combined rich picture. This was the objective of the second round of problem-mapping FGDs (schedule: Table 5-1), and the GMB was guided using a script as described in Appendix 5.

These objectives relate to the work of Hovmand (2014), which outlines four essential components for an effective GMB:

1. Teamwork: GBM sessions are best conducted by teams rather than individuals. The high workload in facilitating group discussion, building a model, and taking notes makes GMB difficult for individuals. A GMB team usually consists of:

   a. Facilitator: to lead the session and facilitate group discussion.
   b. Modeller: to convert the group discussion into a model and display this to the participants.
   c. Recorder: to take notes and record the group discussion for later reference.

d. Runner: to assist all team members.

2. A Boundary Object or Visual Representation of the model: These may include behaviour-over-time graphs, causal loop diagrams, or rich pictures. They are sufficient to show participants key factors and the relationships between them and are accessible and modifiable by all participants. We used an app called SESAMME[9] (Appendix 6) to create the visual representation of the model.
3. A Script: A Script is a document outlining a logic series of steps or exercises that the GMB session will follow in order to achieve outputs, such as a model. The activities or steps within a script usually fall into four categories:

   a. Divergent: designed to produce an array of different ideas (e.g., brainstorming).
   b. Convergent: designed to categorise or cluster ideas.
   c. Evaluative: designed to choose between options.
   d. Presentation: designed to update or educate participants.

4. Participants: These were selected based on the stakeholder analysis that we performed during the problem-scoping activity. It is generally best to engage these groups of people in separate GMB sessions so that the discussion can be frank and open. Therefore, for each village, we spilt our participants into two separate FGDs.

3.6.2.2 Rounds of problem-mapping FGDs

For each village, two rounds of problem-mapping FGDs were held individually with each of the participant groups. To ease document navigation, the explanation for the participant groupings and the FGD rounds are presented in Chapter 5 (Section 5.1.1.2 and 5.1.1.3, respectively) preceding the presentation of the problem-mapping results.

3.6.2.3 Location selection of the problem mapping FGDs

The problem-mapping FGDs was held in eight of the twelve villages previously visited in the problem-scoping activity (Schedule and village locations: Table 5-1, Figure 3-4). Each village received two rounds of problem-mapping FGDs.

3.6.2.4 Participant recruitment and criteria in the problem mapping

Participant recruitment in each of the target villages (Section 5.1.1.1) was done using a similar procedure to that of the problem scoping (Section 3.6.1.3). In each round, per village, one problem-mapping FGD was held for two stakeholder groups (Table 5-1). Participants of the first

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[9] The acronym stands for Socio-ecological Systems Application for Mental Model Elicitation.

round of FGDs were invited to the second round. The participant criteria were determined based on the results of the problem scoping (Section 3.6.1.3).

3.6.2.5 Data outputs and method of analysis in each problem-mapping FGD

Each problem-mapping FGD generated data outputs consisting of:

- Digital rich pictures, or 'SESAMME maps', depicting the structure and feedback loop underlying the same topic problem.
- Digital photos and audio recordings of the FGD activities.
- Written notes.
- List of FGD participants.

The justified integrated CLD from Round Two of the problem-mapping FGD was part of the information used to develop **CLD 3** as the final version (Section 5.5).

The resource variable state and variable trends information produced from the problem mapping were used to define the reference mode of the problem in the following causal modelling activity (Section 3.6.3).

3.6.3 Activity 3: Causal modelling

An outline of the causal modelling activity can be found in Chapter 5 (Section 5.2.1), which precedes the presentation of the causal modelling results.

3.6.4 Activity 4: Supplementary interview for causal model justification

The explanation for the supplementary interview can be found in Chapter 5 (Section 5.2.2), which precedes the presentation of causal modelling results.

3.6.5 Activity 5: Dynamic modelling

Stock-and-flow (SF) modelling was conducted to understand the dynamic behaviours generated by the feedback structures delineated in the final version of the causal model (CLD 3) (Cavana & Maani 2000; Chapter 6 & 7: Sterman 2000). The modelling was done through a computation that simulated the accumulation and the rate of change of materials and/or information related to the variables defined in the causal model (Sterman 2000). Each of the modelling steps performed is explained in the following subsections in consecutive order.

3.6.5.1 Step 1: Stock-and-flow diagram construction

In this activity, we translated each causal link between variables in CLD 3 more rigorously into the stock-and-flow diagram (SFD). We used the Stella® Architect software (ISEE Systems, NH, USA, http://www.iseesystems.com) to construct the SFDs and perform the simulations. The software provides a user-friendly interface that allows researchers with limited programming experience to generate and access algebraic equations and perform computation during and after constructing the SFD. An SFD comprises four typical building blocks: (1) stock; (2) flow; (3) converter (or, auxiliary variable); and (4) connector (Figure 3-5). As described by Yuan et al. (2011, p. 605):

> A stock collects all those in-flows and also serves as the source from where out-flows come. A flow serves as a vehicle to deliver information [or, materials] to, or drain information from the stock. The value of a flow can be positive or negative. A positive flow is an inflow and will fill in the stock, and a negative flow is an outflow draining the stock. A converter or auxiliary variable has a utilitarian role in selecting proper values and functions of parameters in the model. The connector is an information transmitter connecting elements.

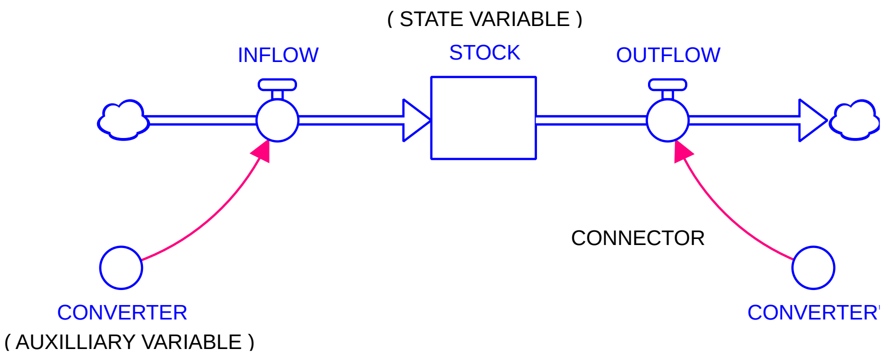

Figure 3-5. A simple SFD structure built using the Stella® Architect software showing stock (depicting state variables, represented by a rectangle); flows (depicting processes going in and out of the state variable, represented by valves with block arrows), auxiliary variables (or 'converters' depicting algebraic and/or graphical relationships, or fixed parameters, symbolised by a lined circle) and connectors (depicting information flows or interrelations, represented by simple arrows).

Essentially, CLDs and SFDs are different versions of the same model of the system. While the arrows and words in CLDs are mainly used to qualitatively visualise feedback relationships (e.g., the loops), the structures of the SFD were treated as visual 'building blocks' that guide the Stella® Architect software to map the order of execution of computations to simulate the dynamics of materials in the stocks and flows. An example of a CLD translated into an SFD can be found in Figure 3-6. In each SFD, building blocks, constant values, mathematical equations, and/or built-in command syntaxes (henceforth, referred as a 'Stella® equation'[10]) were able to be written directly to specify the desire model parameter or conditional rule. Due to the size of the SFD that evolved during the construction, the SFD structure was organised into different groups, referred to as

[10] The Stella® equation documented in this manuscript follows the online software manual published by ISEE systems at https://www.iseesystems.com/help.

‘sectors’. In the software’s user interface, each sector was indicated by a rectangular border that contains SFD elements t0 represent functionally-related structures.

A large number of the SFD elements were arrayed to allow the team to simulate different computations by using the same SFD structure, thus avoiding the visual complexity of the diagram. When arrayed, each building block of the arrayed SFD represents one or several array dimensions (i.e., ‘categorises’) each of that consists of two or more elements. For example, the ‘age’ dimension consisted of ‘young’ and ‘old’ elements would allow the modeller to specify two Stella® equations for the building blocks (or, variables) arrayed by ‘age’. An additional dimension (i.e., 2 dimensions of each that has 2 and 3 elements) means more similar, or different Stella® equations can be defined up to the total permutation of the elements (2 x 3).

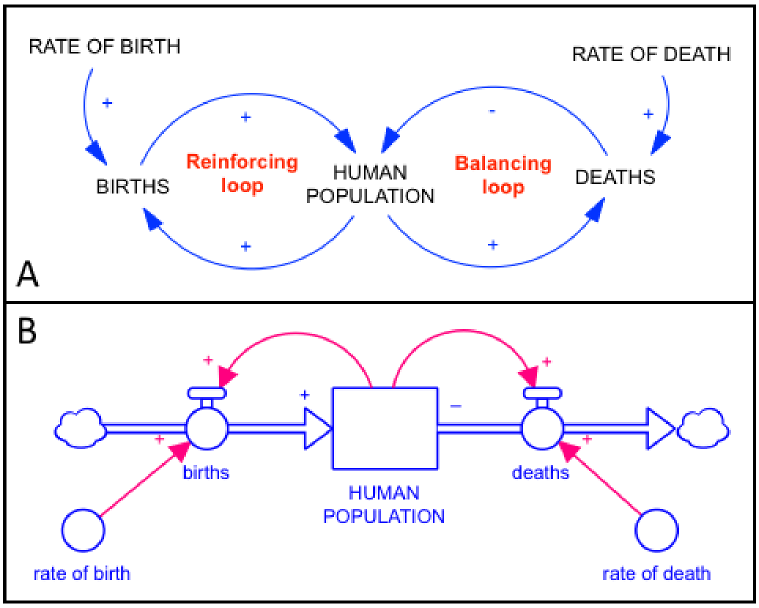

Figure 3-6. An example of a CLD (Box A) translated into an SFD. The ‘human population’ state variable in the CLD is represented as a stock in the SFD. The CLD highlights the reinforcing and balancing feedback loops that regulate the human population dynamics, which are not depicted in the SFD. Instead, the SFD demonstrates that human population is positively influenced by the inflow of birth as a product of the fraction of the human population and the rate of birth of each human fraction, as well as negatively by the outflow of deaths as a product of the fraction of the human population and the rate of birth of each human fraction.

3.6.5.2 Step 2: Model parameterization

After the SFD (or, stock-flow model [SFM]) was constructed, a various secondary social, economic, and biophysical information was gathered to develop an estimation of the numerical values and formulation of mathematical conditional rules to be simulated (Graham 1976); this process is commonly referred to as ‘parameterisation’. The values and rules were defined as relevant and specific as it was possible to represent the ‘base case’ or the most recent real-world conditions or processes associated with the study site within the constraint of the team's working time.

At the time of the study, peer-reviewed scientific data originating from the Selayar Island study area was found to be very limited for justifying the larger portion of the model parameters. Thus, the parameters were defined predominantly by combining:

1. Secondary data collected in the area (e.g., grey literature: mainly government reports and reanalysis of the most recently available datasets of socio-economic and/or biophysical surveys from Selayar).
2. Proxy secondary data from other study sites that provide information with the closest relevance to the social or ecological situation in Selayar.
3. Modellers' assumption derived from the information captured in the problem mapping activity (Section 3.6.2).

Given that the *in situ* existing data was limited, the number of parameter variables was estimated through data aggregation. This means that several data from the secondary information were used to determine parameter input values or conditional rules that reflected the information/variable in the SFD. For example, in the modelling work of McClanahan (1995), the parameter value for the weekly average of fish catch per fisherman was derived from several data (or, 'aggregate' value) by calculating existing data of the total number of fishermen in the village, daily fish catch record, and individual average of fishing trips per week. Other parameter variables were estimated through data disaggregation. This means secondary data based on aggregate values such as statistical summaries were 'broken down' and re-analysed to obtain smaller units of data that reflect the parameter information. For example, to estimate the proportion of male retirees, I multiplied the number of retired males by the size of the total male population divided by total population.

The collation of secondary information is described in Section 3.6.6.

3.6.5.3 Step 3: Model testing

Prior to the utilisation of the stock-and-flow model for the simulation-based analyses, several tests were conducted to 'validate' the model by means of establishing "confidence in the usefulness of the model with respect to its purpose" in relation to the "validity of the internal behaviour of the model, not its output behaviour.... [nor the] … the right behaviour for the right reasons" (Barlas 1994). SFD structure and equation were revised or corrected during the tests that are explained in the following subsections.

3.6.5.3.1 Structure verification and boundary adequacy check

During the diagramming phase, the SFD was regularly examined by the members of the team for structure verification and boundary adequacy (Sterman 2000). Structure verification was done to ensure that the SFD structure conformed to the real-world conditions. The boundary adequacy check was done to see whether that the SFD is appropriate to the boundary of the system of interest by ensuring that the selection of variables included and excluded appropriately for the level of the represented system. The check involved the construction of an influence diagram derived from the final causal model (CLD 3) which was initially drawn to provide the modeller with an 'overview' of the variables, processes, and directions of influence that guide the diagramming of the SFD. In the SFD, state variables from the CLD were mainly represented as stocks and other variables and/or processes as converters and/or flows. Both the influence diagram and the literature-based key concepts and/or generic models were used by the team when disaggregating or aggregating variables, processes, and connections from the CLD into the SFD.

3.6.5.3.2 Unit consistency test

Following Sterman (2000), a test known as 'dimensional consistency' test was performed to check whether (i) the left- and right-hand sides of all equations had consistent units; and (ii) the equations for the flows (that computes the rate of change) were dimensionally consistent by means of the materials/information from the stock conserved in the flow chains all have the same units of measure; and (iii) there are no accidental "scaling" parameters that have little or no real-life meaning. The test was applied to all equations written in each of the SFD elements (stocks, flows, converters) and conducted automatically by the Stella® Architect software. A warning message will be displayed if any assigned units are incorrectly defined.

3.6.5.3.3 Mass-balance test

The mass-balance test (also known as 'conservation of mass' test) was intended to examine if the model would render violation of real-world conditions in the conservation of physical materials and energy (Hannon & Ruth 2014). Mass-balance tests were applied only to model sectors that include stock(s) connected to multiple flows.[11] These were conducted each time a stock-flow structure segment was developed and using hypothetical parameter input values. For each tested sector, an SFD was prepared specifically for the test in order to calculate the difference between the number of materials (mass) conserved in the inflows and the total materials conserved in the stocks and outflows. For each test, the difference value was represented by the "check mass balance"

[11] The tests were conducted under the Stella model file "sfm phd r11 test1 mass-balance.stmx", which can be obtained by email request to S. Taruc.

converter. A ‘balanced’ mass is described as unchanging difference value over the period of the simulation. The constant difference value indicates that there is no mass is artificially generated in the inflows, stocks and/or outflows.

3.6.5.3.4 Extreme conditions test

This test was conducted to examine whether the equations embedded in the model would generate output behaviour of variables that plausible in real-world conditions when hypothetical-but-reasonable maximum or minimum parameter input values are applied to the model. Following Sterman (2000), the test was conducted only to those model sectors or stocks that received exogenous influence and involved applying an ‘extremely-high’ and/or ‘extremely-low’ parameter input value starting from the mid-period (year 10) of the simulation time span (20 years). Prior to the test, all stock-flow model components/variables were been manually inspected for the consistency of the equations applied in the arrayed structures or elements. This included ensuring that arrayed SFD elements representing similar process/influence were assigned the same equation structure but calculated the different dimensions of the arrayed variable(s). A new model file version was made and renamed after each test; as each test might have identified inconsistencies, the associated model structure or equation was revised[12].

3.6.5.3.5 Sensitivity test

The analytical objective of this test was to identify the parameters with (i) a significant influence on the simulation output of the state variables generated using the model, and (ii) insignificant parameters that could be eliminated in the model or given less attention in the analyses (Hamby 1994). The influential parameter variables, together with relevant variables identified in the problem-mapping activity (e.g., decision variables), were then treated as potential leverage points that would be tested as policies using the SFM. Accordingly, sensitivity tests were applied only to ‘policy parameters’ or parameters that were directly controllable or manageable by the problem owners (e.g., resource users) or the stakeholders of the problem (e.g., natural resource managers).

There is no fixed approach or method in which sensitivity tests, such as mathematical procedures and techniques, are subject to various modelling situations (Iman & Helton 1988; Matott, Babendreier & Purucker 2009). Following Hamby (1994), the ‘one-at-a-time’ method was chosen in view of the test’s main aim of testing developing policy recommendations, and partly for model development. The method is begun by varying the input value of one parameter at a time by +10% and -10% percentage of the base case value (base case fixed value input parameters:

[12] The file of the newer model version developed after the last revision in the last test is named “sfm phd r11 test0 base case10.stmx”, which was parameterised using hypothetical input values and can be obtained by email request to the author.

Appendix 22 & Appendix 23). The three input variations (from -10%, base case, and +10% inputs) were then simulated while keeping the other parameters constant for a simulated time frame of 1040 weeks. For each observed state variable (i.e., variables that define the problem), the output values at the final week were examined for the deviation of the output value of the +10% or -10% input variation from the output value of the base case input. The sensitivity of a particular state variable to each of the tested parameters was then gauged by ranking the tested parameters based on each of the resulting output deviations. A higher deviation means the higher parameter influences the observed state variable. Similar to the extreme condition test, simulation outputs were observed only for selected array dimension element(s) that represented the state variables and limited state variables that received the closest influence by the parameter (i.e., in the same SFD sector).

3.6.5.3.6 Behaviour reproduction test

The purpose of this test was to examine whether the changes in the output values produced in the simulation (or, the 'behaviour') were in agreement with the observed behaviour in the real system. The test was done after model parameterisation was completed, which then allowed for a simulation run of a model reflecting the 'base case' situation of the system (i.e., the year 2016 condition of Selayar Island). The modelled behaviour from the graphical and tabular simulation data output generated using the Stella® Architect software was then compared with the reference modes (e.g., BOTGs) defined earlier in the causal modelling activity (Section 3.6.3) and also to historical trends recorded from cases in Selayar or other locations.

3.6.5.4 Step 4: Policy design and modelling

In this step, and henceforth, the term 'policy' refers to changes to a single internal variable. 'Strategy' refers to the combination of a set of policies and still deals with internal and controllable changes (Maani & Cavana 2007; Sterman 2000). Following the same authors, the design of a policy (or policies) was determined, based on several sources of information (mainly of the problem owner's perception) (i.e., the decisions variable identified in the problem mapping: Section 3.6.2.2), the outcome of the sensitivity test (i.e., policy parameters influential to the observed output variables), and/or relevant policies suggested in the peer-reviewed literatures. Each policy was represented in the model by either modifying (1) the structure of the stock/flow model, (2) the values (constants), and/or (3) equations of conditional rules/assumptions (i.e., arithmetic and/or non-linear expressions [i.e., dimensionless parameter graph]).

3.6.5.5 Step 5: Scenario planning and modelling

In this step, and henceforth, the term 'scenario' refers to variations of external conditions in the future. The scope of the scenario was defined by a selection of uncontrollable parameters related to future uncertainties based on the findings from peer-reviewed literature, or based on the results of the uncertainty tests of those that have a significant influence on the observed output variables (Cavana 2010). Scenario(s) was represented in the model following a similar approach as for the policies.

3.6.6 Activity 6: Secondary information collation

Given the data-poor study area, secondary information sources such as peer-reviewed literature, grey literature, and pre-existing datasets were used to address data gaps, mainly during the development of the models (i.e., the causal and the dynamic models) and for the justification of key findings in the analyses of the modelling results.

For the dynamic (stock-and-flow) model, parameters related to local biophysical environment conditions were largely estimated from best-available secondary sources. Specifically, variables related to the status and the behaviour of the biotic resource components (e.g., current species abundance, species growth rate, natural recruitment, and mortality) were largely estimated from ex-situ observations or experiments from areas outside the Selayar region or of a larger spatial scale. Parameters representing local social and economic conditions were largely estimated from statistical reports by the local government and the most recent data of household socio-economic conditions (Section 3.6.6).

3.6.6.1 Information from grey literature

We collected a substantial amount of grey literature (i.e., research that is either unpublished or which has been published in non-commercial form) both during the causal (Section 3.6.3) and dynamic (Section 3.6.4) modelling phases. For this research, the literature mainly comprised government reports, research reports by non-academic institutions (e.g., civil society organisations), and theses/dissertations. During the course of the research, the literature was collected according to analytical requirements, particularly during (1) CLD development and analysis (Section 5.2.1.1), and (2) qualitative model parameterisation (Section 3.6.6). A data collation table was prepared by the team, which was used to guide retrieval of identified existing data in various repositories, to identify data gaps due to the absence of secondary information that would be addressed by collecting primary data or re-analysing existing data (e.g., socio-economic survey: Section 3.6.6.2). The table is populated with information as follows:

- Name of the variable associated with the topic problem
- Variable type in the stock-flow model
- Units
- Existing datasets
- Existing proxy datasets
- Custodian of the data set
- Is the data temporal (Y/N)?

- Years for which the data exists
- Who to contact to get the data
- The team member who obtained the data
- The timeframe for obtaining the data
- Who else needs the data
- How the data will be shared
- What to do if there is no data

3.6.6.2 Information from re-analysis of data collected by Amanda Lindsay in the Bio-LEWIE household survey

3.6.6.2.1 Overview of the survey

Information in this section is developed based on an email Amanda Lindsay (AL) sent to the CCRES project member on 17 October 2016. AL was also the team leader for a household survey that formed part of the Bio-LEWIE modelling activity in the CCRES project. At that time, AL was undertaking PhD candidate based in the Resource Economics and Policy Lab at the University of California, Davis, under the supervision of Professor Jim Sanchirico.

A questionnaire-based household survey was done over a six-week period from September to October 2016 by a team (led by AL) of 16 enumerators made up of current and former students from Hasanuddin University, Makassar, Indonesia. The data was collected using tablets and Open Data Kit data collection software. The enumerators worked in pairs, and at least one enumerator per group was fluent in the local language, Selayarese. A total of 487 households were surveyed from 12 of the 52 villages in the six sub-districts of Selayar Island.

The surveyed villages included Bonea Timur, Maharaya, Mekar Indah, Bontomarannu, Benteng Selatan, Kalepadang, Bontotangnga, Bontolebang, Binanga Sombayya, Laiyolo, and Laiyolo Baru, Appatanah. From each of the villages, two sub-villages were selected for the survey. Working with the head of the sub-village, the survey coordinator assembled a list of the names and locations of the households. Roughly 40 households from each village were randomly selected for sampling.

Household surveys gathered information about the household roster and demographic information, household production activities (fishing, agriculture, livestock, enterprise), purchases, food security, and finance. Of the 487 households sampled, 152 households engaged in fishing activities, 245 households engaged in agricultural activities, and 180 households operated small businesses. Households engaged in fishing activities were asked questions about fishing trips in the wet and dry season. Details about the location of fishing activities, boats and gear used, time spent fishing, and fish harvest were gathered for unique trip types. Households could define up to 3 types of fishing trips per season, distinguished primarily by location or gear used. Of the 152 households engaged in fishing activities, 144 households fished during the dry season and 116 households fished during the wet season.

A total of 256 registered businesses were also surveyed from Benteng, Benteng Utara, and Benteng Selatan. The survey coordinator compiled lists of the names and locations of registered businesses. Business surveys collected information detailing each business's use of hired labour, expenses, sales, and financing. Where applicable, information on fish inputs was collected. Of the 256 businesses surveyed, 3 were hotels, 50 were restaurants, and 108 were shops. Of the 50 restaurants surveyed, roughly half of them purchased fish inputs.

3.6.6.2.2 Method for re-analysing the pre-existing survey data

A descriptive statistical method, such as mean, frequency count, and percentage was used to analyse the Bio-LEWIE household survey dataset. Mean calculation was mainly used to describe the average condition of the surveyed variables. Prior to the calculation, the respondent sample data were filtered and grouped according to the information criteria (e.g., fishing household group criteria). Raw data selection, filtering and grouping, and calculations were all conducted by AL to complete a list of auxiliary information (e.g., model parameter variables) based on the list of missing data that the team developed. Average values of the variables were then tabulated, and can be found in Appendix 17.

Chapter 4 Defining the dynamic problem

This chapter presents and discusses the results from the first activity in this research, the problem scoping (for related methods, see Section 3.6.1). The first part explains the profile of the focus group discussion (FGDs) held with members of fishing villages that were selected in consultation with a local collaborator. Section 4.1 presents the results mainly using information extracted from the FGD output materials, which are (1) rich pictures about the participants' livelihood; (2) lists of prioritised livelihood problems, and (3) bullseye diagrams of the stakeholders related to the problem. Section 4.2 discusses the contribution of the problem scoping to articulating a dynamic problem mainly based on the problem stakeholder's experiential knowledge (using outputs 1 & 2), and helping to determine the groupings of participants invited in the problem mapping FGDs (using output 3; Chapter 5). The term 'dynamic problem' refers to a problem that involves one or more variables (or, factors) and which changes over time.

4.1 Results from the problem scoping

4.1.1 Problem-scoping FGD profile

4.1.1.1 Locations and schedule of problem-scoping FGDs

Of the 23 villages[13] located on Selayar Island (including the adjacent smaller island of Gusung Pasi), thirteen were considered as 'fishing' villages. These villages are concentrated on the west side of the island (Map: Figure 3-4). According to the local collaborator (Pers. Comm., Penrang A., 2015), the settlement pattern was due to the low coast, beach areas on the western side of the island that are preferable for boat berthing and coastal settlement, compared to the high coastal cliff areas on the eastern side. Towards the southern tip of the island, the island terrain features deep red soil (the northern end is limestone dominated), and agriculture is a major activity in the southernmost two districts.

Twelve problem-scoping FGDs were conducted between 10-13th of August 2015 and included one FGD for each of the twelve fishing villages (Schedule: Table 4-1, Map: Figure 3-4) that span the island's six districts. Appatanah, a village located at the southern tip of Selayar Island, was excluded due to time and access constraints during our fieldwork.

Table 4-1. The schedule for the problem-scoping FGDs. Note: # = A *kelurahan* (sub-sub-district) of Benteng sub-district, ## = A *dusun* (sub-village) of Harapan village.

FGD no.	District / *Kecamatan*	Village / *Desa*	FGD date
1	Bontomatene	Bungaiya	10/08/2015

[13] The term 'village' here refers to the *desa* administrative boundary defined in the Law Number 6 of 2014 Concerning Village, that includes, at least, 3000 residents or 600 household breadwinners.

FGD no.	District / *Kecamatan*	Village / *Desa*	FGD date
2	Bontomatene	Barat Lambongan	10/08/2015
3	Buki	Mekar Indah	11/08/2015
4	Bontomanai	Barugaiya	13/08/2015
5	Bontomanai	Parak	12/08/2015
6	Benteng	Benteng Utara[#]	10/08/2015
7	Bontoharu	Bontolebang	13/08/2015
8	Bontoharu	Kahu-kahu	12/08/2015
9	Bontoharu	Bontoborusu	13/08/2015
10	Bontoharu	Bontosunggu	11/08/2015
11	Bontosikuyu	Harapan/Dodaiya[##]	11/08/2015
12	Bontosikuyu	Patikarya	11/08/2015

4.1.1.2 Participants of problem-scoping FGDs

The criteria for selecting the problem-scoping FGD participants were decided after consultation with the local collaborator. They would be either:

1. Villagers involved in fish harvesting (e.g., capture fisheries, fish farming, or gleaning) for either subsistence or income generating purpose; and in utilising harvested fish (e.g., fish traders, collectors, or food processors); or
2. Village residents who influence village fishery activity, such as the representatives of village government offices or cultural figures (e.g., elders and religious leaders).

Participants of the problem-scoping FGDs ranged from 10 to 15 invited village residents who were participants in village fishery activity. The number of participants was considered manageable for the 4 team members (S. Taruc, S. Kusumo, N. Setianto, and L. Adrianto) who were available to facilitate the FGDs. Based on the attendance list (Appendix 7), a total of 155 people would be participating in the problem scoping. As shown in Figure 4-1, the FGDs were attended by male participants who were fishers, village administrative staff, village public figures, and freelance workers (Chart A). The female participants were from the village women's groups, household-level enterprises, or village administrative staff (Chart B, Figure 4-1). A balanced gender composition was initially assigned by the local collaborator during the listing and invitation of candidate participants from each village; however, the balance was not maintained for all of the FGDs. This was largely due to candidate absence, where a person was replaced by someone in the household of a different gender. This resulted in a male-dominated FGD participant list (Chart A Figure 4-1).

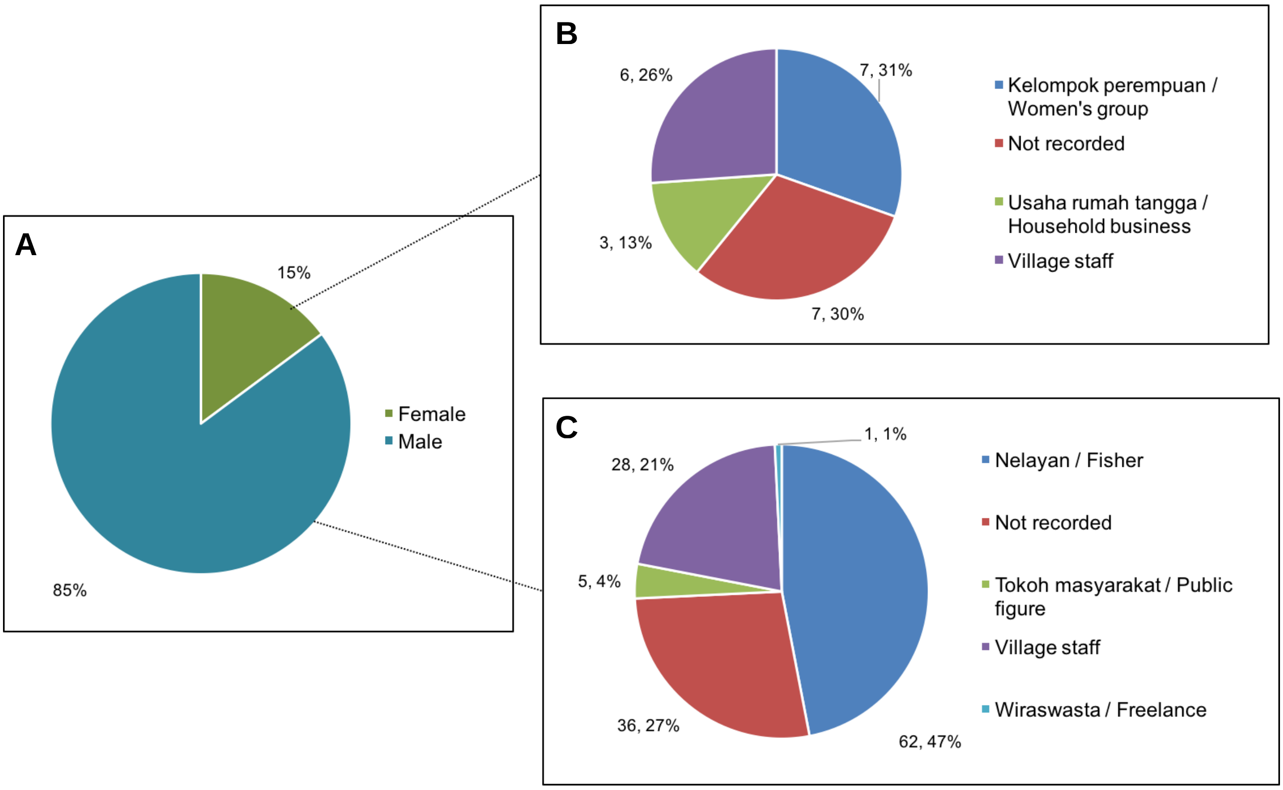

Figure 4-1. The pie charts indicate problem-scoping FGD participant composition by gender (Chart A) and participant occupations from each gender group (Female: Chart B, Male: Chart C). The pie chart labels indicate the percentage of the gender composition (Chart A) and occupation type (Chart B and C). Total participant count = 155. The charts summarise information from FGD participant attendance list data (see Appendix 7).

4.1.2 Problem-scoping FGD visual materials developed by participants

The 12 problem-scoping FGDs conducted produced a total 36 visual materials, as participants of each FGD generated one rich picture of the village livelihood, one list of problems related to the livelihood ranked from the most important, and one bullseye diagram of stakeholders related to the problems (for photos of the materials, see Appendix 10).

4.1.2.1 Scoping output 1: Rich pictures about livelihood

4.1.2.1.1 Information about livelihood activities

Based on information related to livelihood activities extracted from the rich pictures (visual materials no. 1 in Appendix 10), fishing was found to be primary income-generating activity in the village, and was conducted traditionally using an artisanal method. From the seven villages where trend information was identified, participants perceived that fishing activity had been increasing, influenced by an influx of fishers to the village and a demand to increase fishing efforts. A similar number of villages had organised surveillance of their village fishing grounds either during fishing activity or at a separate time. With the exception of Benteng Utara and Dodaiya, most village fishing households were found to be engaging in other natural resource-based livelihood activities, such as crop farming, livestock farming, traditional fish and seaweed farming, salt production, and small-scale tourism activity. However, these activities were not considered to generate the primary source of income for households, or were conducted with less intensity than fishing.

Table 4-2. Summary of information related to livelihood activities that were extracted from the rich pictures (marked with number 1, and Table 2 in Appendix 10) and discussion notes. (Note: Black table cells refer to unidentified information).

Primary livelihood activities	Primary activity trend in the past	Facilitators' notes	Non-primary livelihood activities
• Traditional fishing • Seaweed farming • Fish farming (Aquaculture) • Mobile lift net fishing • Fixed lift net fishing	• Increasing traditional fishing • Gradually increasing traditional fishing.	• Fishing is increasing due to the immigration of fisher. • Fishing is increasing due to the increase of the local population. • A considerable number of villages conduct independent marine surveillance with various capacities ("As much as our effort allows"). • Fishing becomes primary since the '90s.	• Coconut processing • Fish farming • Fish product processing • Livestock farming • Plantation/crop farming • Salt farming • Sand mining Marine surveillance • Tourism service • Tourism ("Turtle village")

4.1.2.1.2 Information related to livelihood resources

Based on the tabulation of information related to livelihood resources extracted from the rich pictures in Table 4-3, all fishing activities in the villages relied on fishing resources in inshore/reef areas, or *ikan karang*, and coral reef habitats were the predominant fishing grounds (also based on the fishing ground depicted in the rich pictures in all villages – e.g., Bontolebang Figure 4-2). From the same table, declining fish catch in the past was identified in almost all villages, except Bontosunggu, where fishers relied not only on traditional boats but also on traditional mobile fish pens/lift-nets with larger engine capacity. The decline in fish catch was perceived to be caused by catch taken by fishers outside the village operating that may include larger fishing vessels, past events of destructive fishing activity, and weather disturbances. The declining condition of fish stocks or the catch were either identified as resulting from the perceived reduction of fish harvested, or higher effort required to achieve the desired catch. The condition of the coral reef village fishing grounds was mostly perceived to be declining in the past. Improved reef condition was perceived in several villages where destructive (e.g., cyanide, blast fishing) activities had been reduced due to interventions to destructive fishing (e.g., independent marine surveillance, Table 4-2) partly led by a government program (COREMAP). All villages have access to the natural resources within the village area on which households rely to maintain their non-primary income generation activities. However, the diversity of resource differs from one fishing village to another.

Table 4-3. Summary of information related to livelihood resources extracted from the rich pictures (Photos marked with number 1, and Table 3 in Appendix 10) and discussion notes. < = only to a small number of households.

Resources associated with primary livelihood activity	Past resource trends	Facilitators' notes	Resources associated with non-primary livelihood activity
• Reef fish • Coral reef Seaweed • Seagrass • Pelagic fish < • Sea turtle • Benthic fish • Crustaceans • Shellfish • Swimming crab (Mangrove crab)	• Declining fish catch • Declining reef condition • Improving reef (recently) • Improving fish catch < • Varying fish catch < • Increasing fish catch <	• Declining reef due to blast fishing • Improving reef due to protection • Declining fish catch due to fishing by fishers outside of the village (with bigger vessel), storms, and trash • Declining fish catch to dolphin • Declining reef due to cyanide fishing • Improving reef due to lesser cyanide fishing, and the recent government intervention program to cyanide fishing • Declining catch due to weather disturbance to fishing • Declining pelagic fish catch due to competition with external fishers with a larger vessel. • Reef condition worsens as reef location further from the coast due to uncontrolled blast fishing.	• Bamboo • Beach (Tourism) < • Cashew • Cassava • Catfish < • Cattle < • Chicken • Chocolate • Coconut husk • Coconut processing • Corn • Crops • Forest (Protected) • Groundwater • Livestock • Mangrove • Milkfish (Farmed) • Orange • Peanut • Sand (as a construction material) • Sea turtle (For nursery activity in the neighbouring village) < • Shrimp (Farmed) • Shrimp paste • Swimming Crab (Farmed)

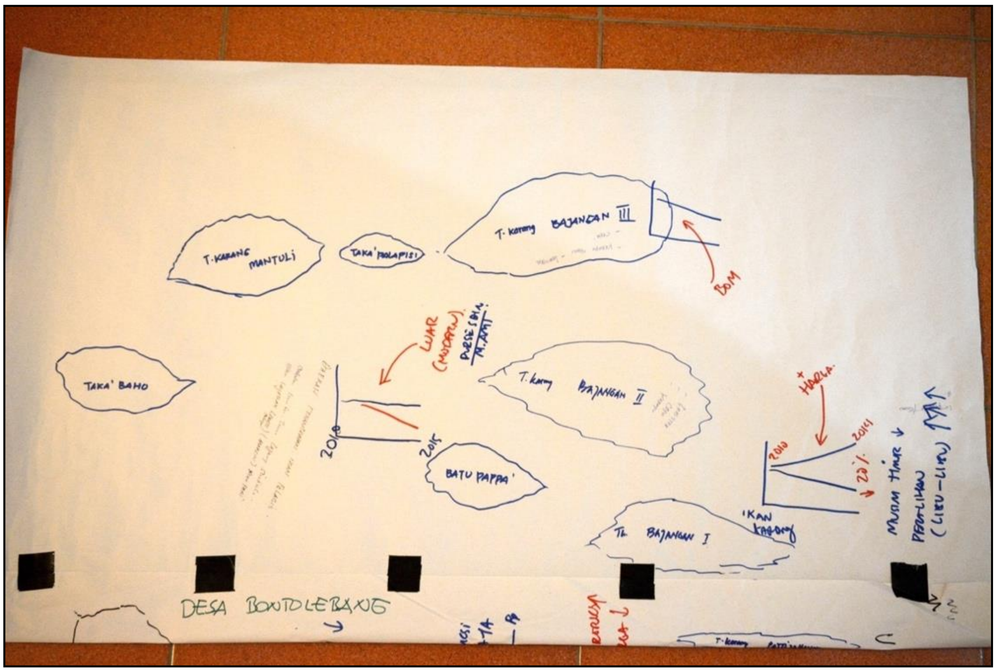

Figure 4-2. One example of a fishing ground in a reef area drawn by participants in Bontolebang Village.

4.1.2.2 Scoping output 2: List of livelihood problems

In each of the twelve FGD, all participants were able to develop and agreed to a single list of key problems related to the previously identified livelihood activities and ranked the problems in order of priority (example: Figure 4-3, visual materials no.2 in Appendix 10).

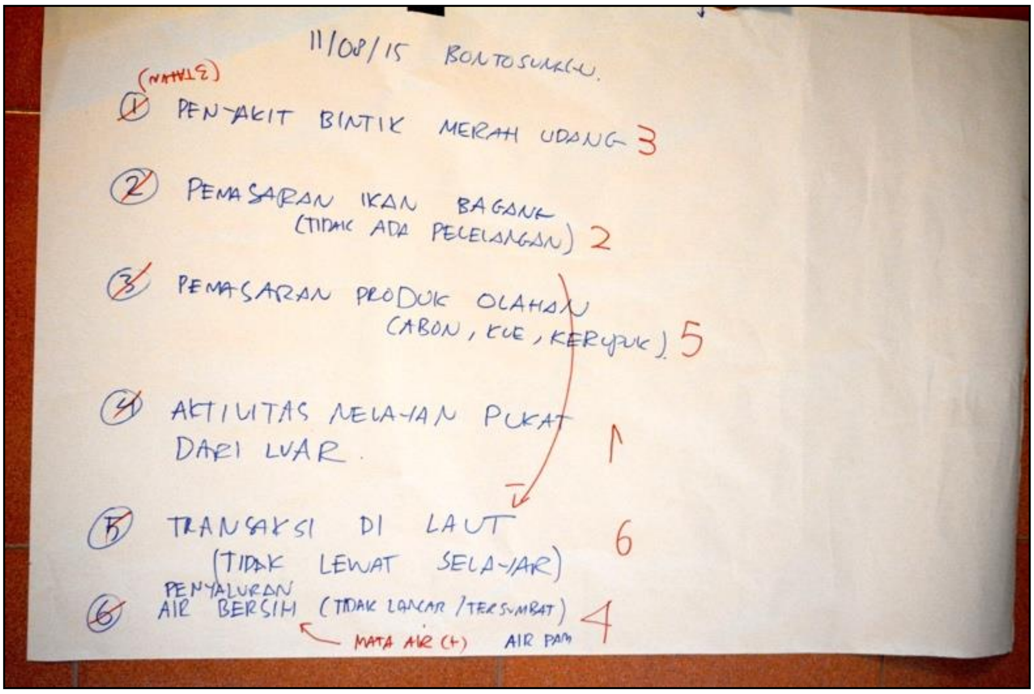

Figure 4-3. An example of the main livelihood problems listed by the participants from Bontosunggu Village and ranked based on the level of importance depicted by the numbers assigned.

From the extracted information in Table 4-4, in general, the problems were associated with natural resource conditions, the fishing activity of the local fishers or those outside the village, gear catch capacity, fish sale price, the marketing of fish, cash assets and skills linked to non-fishing livelihood activity, and access to clean water and electricity. In relation to fisheries, other than in Mekar Indah, Bontolebang, Parak, and Dodaiya villages, the majority of FGDs (*desa* names marked in bold, in Table 4-4) identified declining fish catchs and coral reef conditions as part of their top three most important problems; and several villages also reported that fishing activity contributed to the decline (e.g., blast and cyanide fishing, increasing number of fishers operating) (problems in bold text, in Table 4-4). Based on this information, one of the topics that the team (see Section 3.5) defined as a problem of interest was "declining reef fishery" which was further investigated in this research.

Table 4-4. Summary of problems identified in each FGD arranged in order of perceived importance, (extracted from the lists) (Photos marked with number 2, and Table 4 in Appendix 10). Bold font is used to highlight desa in which the topic problem was identified.

FGD no.	Desa	Perceived main problems listed in order of importance
1	**Bungaiya**	1. **[Undesirable] impact of cyanide and blast fishing** 2. Limited catch ability (traditional fishers) 3. **Declining fish catch** 4. [Lack of] cash capital for household industry 5. **Market fish out of Selayar**
2	**Barat Lambongan**	1. **Poison use [in fishing] (from the *tuba* plant root, kills fish and damages reef)** 2. **Coral reef degradation**

FGD no.	Desa	Perceived main problems listed in order of importance
		3. Lack of cash capital to support alternative income generation 4. **Declining fish catch** 5. **Declining wild fish stock** 6. Uncertain and fluctuating fish price
3	Mekar Indah	1. Lack of clean water 2. Boat sheltering area during bad weather 3. Presence of dolphins that disrupts purse sein fishers 4. Limitation in fishing gear (traditional) 5. **Fish processing facility** 6. Difficulty in supplying wood for boat building
4	**Barugaiya**	1. **Declining fish catch** (due to fishers from outside the village in bigger boats, mobile lift-net boats, and/or no boat for patrolling [village fishing ground]) 2. Abundance of coconut by-products (husks) that were not utilised/processed 3. **Cyanide fishing is still ongoing (damages the reefs)** 4. Land use conflicts between cattle farmers
5	Parak	1. Lack of clean water 2. Low productivity of agriculture-based income generation 3. Limitation in fishing [catch capacity]
6	**Benteng Utara**	1. **Declining fish catch** 2. Fish storage facility 3. **Cyanide and blast fishing still operate** 4. Unstable fish sale price 5. Community member having limited skills and knowledge 6. **Required to fish more often [than in the past] (in relation to no. 1)** 7. Limited cash capital
7	Bontolebang	1. Lack of clean water 2. Limited electricity 3. **Fishers from outside village operating** 4. Low fish sale price 5. Difficulties in marketing farmed fish 6. Limited skills/ability of human resource in agricultural activity
8	**Kahu-kahu**	1. Lack of clean water 2. **Rampant cyanide fishing** 3. External purse seine boats operating that reduces the catch of village fishers 4. Conflict between district marine conservation area and village economic needs 5. Village spearfisher (hookah) competing with the traditional fishers
9	**Bontoborusu**	1. **Rampant cyanide fishing** 2. **Difficulty in monitoring fisher from outside of the village** 3. Limitation in fishing gear catch capacity 4. Lack of fish processing 5. Lack of skills to process cashew 6. Lack of skills in bamboo crafting 7. Organizational platform to manage tourism activity 8. Road access that connects between east and west coast main roads.
10	**Bontosunggu**	1. **Many purse-seine fishing boats from other areas operating [in the village fishing grounds]** 2. **Fish market place for trading catches from the mobile lift-net fishers** 3. Red spot plaguing farmed shrimp 4. Limited access to fresh water 5. Limitation on marketing processed food products (fish floss, cakes, crackers) 6. **More fish being traded at sea (not through the local market in Selayar)**
11	Dodaiya	1. Limited cash capital and skills/knowledge to run fish-raising activity.
12	**Patikarya**	1. [More] bigger waves. 2. **Rampant cyanide fishing** 3. The absence of an organisational platform of fishers (reluctant to make group) 4. The defective boat used for monitoring marine protected area 5. **More mobile lift-net fisher [from another area] operating closer to the shore** 6. Lack of garbage disposal area/centre and toilets 7. Limited fishing gear 8. The difficulty of marketing caught fish

4.1.2.3 Scoping output 3: Bullseye diagram of stakeholders associated with the livelihood.

In all FGDs, participants were able to identify stakeholders through facilitated bullseye diagram drawing (example: Figure 4-4, visual materials no.3 in Appendix 10). However, the Bontolebang Village stakeholder assessment was not finished as the team had to leave the village early before low tide. The first FGD was treated as a pilot and we (see Section 3.5) limited the time to about an hour and a half. As a result, stakeholder identification was primarily focused on three top priority problems, or problems associated with the fishery.

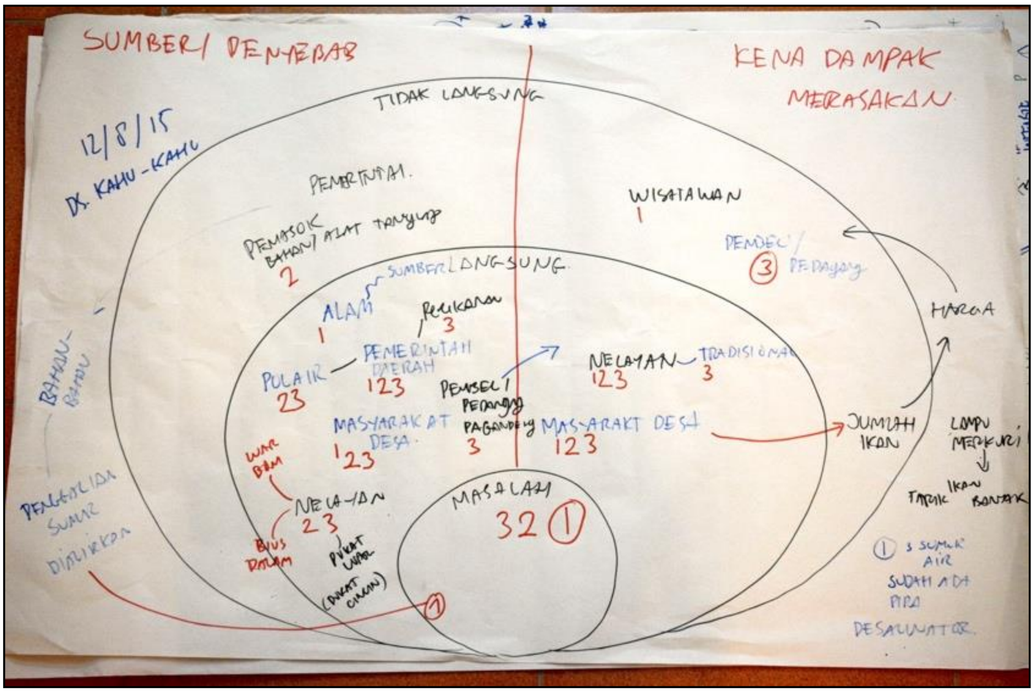

Figure 4-4. An example of a bullseye diagram describing the stakeholders associated with the top three problems (represented by the numbers) as identified by participants in Kahu-kahu Village. The three circles, from the smallest to largest, represent, respectively: (1) the top three problems discussed, and identified stakeholders who are (2) directly and (3) indirectly linked to the problem. Each stakeholder circle was divided into two groups (see the vertical red dividing line) based on those stakeholders who affect (left side) and are affected by (right side) the problem.

Summarising the information extracted from all diagrams (see Table 4-5), the identified problem stakeholders were found to originate from both within and beyond the village. Furthermore, from the diverse stakeholders associated with the top-three problems or fishery-related problems (shown in bold text), several stakeholder groups can be delineated, namely: (i) fishermen, (ii) villagers, (iii) community-based surveillance group/s (if any), (iv) external fishers and destructive fishers, (v) fish traders and destructive fisher patrons, and (vi) government institutions (either village or higher administrative level) related to fisheries management in

Selayar. Overall, the heterogeneity of the identified stakeholders directly linked to the problem were higher than those who were indirectly linked.

Table 4-5. Summary of information related to the stakeholders associated with the problems previously listed by participants, (extracted from the bullseye diagrams) (Photos marked with number 3, and Table 5 in Appendix 10). This table presents only those stakeholders associated with the "declining reef fishery" topic problem.

FGD	Desa	Problem no.	Stakeholders influencing the problem		Stakeholders influenced by the problem	
			Directly	Indirectly	Directly	Indirectly
1	Bungaiya	1	Fishermen from outside of Selayar Fishermen using poison/bomb		Plantation/Crop Farming Fishermen household Villagers	Local government Seafood buyer/consumer
		3	Fishermen from outside Fishermen using poison/bomb Fishermen using a bigger vessel		Fishermen Local government Villagers / Household	Local government Villagers / Household Seafood buyer/consumer
2	Barat Lembongan	1 2 4 5	Fishermen from outside of Selayar Cyanide fishers The COREMAP national government program	Fishermen from outside of Selayar Cyanide fishers Local (village) government	Villagers / fishing households Local fishermen	
4	Barugaiya	1	Fishermen from outside Fishermen using the floating fishing hut Fishermen using poison/bomb\	Local government	Seafood buyer/consumer Villagers / Household Local fishermen	Villagers / Household
		3		Poison suppliers		
6	Benteng Utara	1	Villagers / Household		Local fishermen Villagers / Household	Local fishermen Seafood buyer/consumer
		3	Fishermen using poison/bomb Fishermen from outside		Local fishermen Fishermen	
		6	Fishermen household		Fishermen Fishermen household	
8	Kahu-kahu	2	Fishermen using poison/bomb Villagers / Household Local government Marine police patrol	Poison or bomb suppliers Local government	Villagers / Household Local fishermen Local community	Villagers / Household

FGD	Desa	Problem no.	Stakeholders influencing the problem		Stakeholders influenced by the problem	
			Directly	Indirectly	Directly	Indirectly
			Fishermen from outside Fishermen using a bigger vessel Marine police patrol Villagers / Household Fisheries Office	Local government		Seafood buyer/consumer (Unreadable handwriting)
9	Bontoborusu	1	Fishermen from outside Fishermen using poison/bomb	The local/village community	Fishermen Villagers	Local government
		2	The local/village community Local government (Fisheries Office)			
10	Bontosunggu	1	Fishermen from outside	Fishermen Marine police patrol	Fishermen Fisherman neighbour	Local government Fisherman neighbour
		2	Local government		Consumers Fishermen Middlemen	Fuel traders
12	Patikarya	2	Fishermen using poison/bomb	Seafood buyer/consumer Local government	Local fishermen Local community	
		5	Fishermen from outside of Selayar (using bigger vessels) Mobile lift-net / fish pen fishers	Local government	Local fishermen Local community	Local government

4.2 Discussion

In relation to the first objective of problem identification (see Section 3.6.1.4), the concerned dynamic problem (later assessed as the topic in the problem-mapping FGDs; see Chapter 5) was defined here as "declining reef fisheries". This statement relates to the key findings of the problem scoping that generally indicated a past increase of livelihood vulnerability in Selayar, which is discussed below.

Firstly, the rich pictures reveal that the recent (i.e., 2016) livelihood profile of the surveyed fishing communities in Selayar is largely associated with various artisanal/traditional fishing activities. External to the fishery livelihoods, their supplementary occupations remain dependent on a variety of local natural resources and are mainly in the areas of small-scale agriculture or animal farming. However, this applies only to some fishers or households (since most fishers are breadwinners) with entitlements (e.g., land owned by a family) or access to (e.g., harvest profit sharing with the landlord) terrestrial resources. Internal to the fishery livelihoods, their livelihood inputs mainly range from both reef/inshore and pelagic finfish from capture fishing, invertebrates from gleaning, and seaweeds from aquaculture. As recorded in the discussion notes, one fisher commented that the commodity differentiation was partly the outcome of the strategy for dealing with disruptions to fishing operations such as periods of rough weather that require fishers to operate in more accessible fishing grounds which, therefore, supply different fish species. Similarly, a household's decision to engage in seaweed farming (e.g., participants in Bontoborusu) was mainly related to the avoidance of investments in fishing that was considered to be a higher risk occupation both financially and physically. Although these findings contain descriptions of one-time livelihoods, it is clear that multiple factors (i.e., variables) have been, and are, shaping the livelihood diversification strategy of households; and, at the same time, they offer a strong indication that the fishing communities in Selayar might have been coping with a number of livelihood stressors (Brugère, Holvoet & Allison 2008).

Secondly, an indication of dynamic livelihood stressors was able to be drawn from the past trends of fishery resources (i.e., of fish or fish habitats) that were mostly perceived to be declining. A similar condition was reflected in the three top prioritised problems, including the perceived causal factors, which are mainly the impacts of destructive fishing activities (e.g., blast and cyanide fishing), and the local fishing intensification due to the operation of non-Selayar fishers (or fishers outside their village fishing grounds). Stressors such as financial poverty might have partly prompted fishers/households to resort to destructive practices in order to capture a higher proportion of fish, or particular fish that are highly valued, but with far lower operational cost and time than the common method (Cinner et al. 2011). Furthermore, the team noticed that some of the participating villages had explicitly declared their prohibition of destructive fishing (e.g., Parak, Barugaiya), while some openly admitted their involvement in the activity (e.g., Kahu-kahu). This suggests that social conflicts might have occurred within the Selayar fishing communities in addition to the conflicts with non-Selayar fishers. Therefore, the amalgamation of household-level poverty, inter- and intra-community conflicts, and simultaneous livelihood activities in a particular area might have been augmenting local competition, and therefore increasing local fishing activity for an already declining resource (Béné, Macfadyen & Allison 2007). At the same time, the fish decline might have contributed to further reduction of fish catch potential and also the fishing profit, which ultimately might have made fishers/households poorer and reinforced more destructive activities (Cinner 2011).

With regards to the second objective of the scoping, the proposed participant groups (Section 4.1.2.3) were discussed and finalised with the local collaborator to minimise conflict of interest among participating village members of different socio-cultural backgrounds (for participant criteria and recruitment method, see Section 3.6.2.4, and result: Section 5.1.1.2). Moreover, the diverse set of actors that was perceived to influence the problem of interest was regarded by the author, after the scoping activity, as an indication of a complex systems problem; and this warrants further investigation.

As form of learning process by the FGD participants was suggested to have taken place given the deliberation involved, at least to generate a preliminary overview of their problematic system based on participants' experiential knowledge in the process of inquiry in the problem-scoping FGDs (Raymond et al. 2010; Stern 2005). Although an explicit measurement of the rich picture effectiveness was not being measured, the problem-scoping FGD might have contributed to the development of collective understanding among the participants. Gauging from the group learning indicators proposed by (Bell & Morse 2010), the understanding might have been delivered through (1) the visual communication of the artefacts or metaphors recorded in the output materials (rich pictures, problem list, and bullseye diagram); and (2) the process for the artefact creation itself. In developing the FGD output materials, the team considered that the use of structured instructions/questions during the facilitation was found to be useful in 'dampening' any potential conflicts during group interactions, such as when visualising or describing a livelihood worldview about which the must reach a consensus.

To summarise, for the initial stage of this research, the experiential knowledge about the diverse livelihood activities, the variety of the natural resources, the range of influential actors, and the associated trends that were recorded in this assessment confirmed a dynamic problem illustrating the loss of fishery livelihood performance at the local level. Furthermore, synergistic conditions, such as those arising from interactions between different fishing groups, the declining fish and fish habitat condition, and the influence of external factors (e.g., resource demand, price, and actors' behaviours beyond the village members' scope of influence) aligns well with the systems attribute of fishery-based livelihoods in Indonesia and other coastal tropical region (Section 2.2). The findings of this assessment have partly answered the first question of Main Assessment 1 about the problems experienced by the livelihood system stakeholders. This allowed the team a degree of confidence to address the rest of the questions about the interplay between social and ecological components in the system, which was further examined in Activities 2 and 3 (problem mapping and causal loop modelling, respectively; methodology: Section 3.6.2 & 3.6.3; results & discussion: Chapter 5).

Chapter 5 Formulating a dynamic hypothesis of the problem

In the last chapter, a topic problem was defined with the stakeholders. This chapter explores the next step in the systems thinking method, which is to develop a causal model to qualitatively describe the dynamic hypothesis as to how the topic problem arose. Several activities were involved in the model development process, including: (1) problem mapping, (2) causal loop modelling, (3) an interview-based survey for causal relationship clarification, and (4) secondary information collation. The purpose and methods related to these activities can be found in Sections 3.6.2, 3.6.3, 3.6.4, and 3.6.6; respectively.

The first section presents the results from the first and second round (Section 3.6.2.2) of problem-mapping FGDs where the team facilitated group model building (GMB) activities. The first round was intended for capturing the participants' mental models about the social-ecological systems related to the problem by developing digital rich pictures with the aid of an iPad app. The second round was intended for the mental model update, review, and learning from the mental models of participants in other FGDs. This was done by verifying rich picture elements recorded in other groups that differed from those of the FGD participants.

The second and fourth sections present the results from the qualitative modelling of the problem where a large causal loop diagram was produced by triangulating the mental information in the rich pictures and the information from the supplementary interviews (discussed in the third section). The last section presents key findings from the diagram, including the socio-ecological boundary of the system, the key/state variables, the feedback interactions, and the systems archetypes that provide a general dynamic hypothesis for the manifestation of the social-ecological trap that underlies the topic problem.

5.1 Results from the problem mapping

5.1.1 Problem-mapping FGD profile

5.1.1.1 Locations and schedule of problem-mapping FGDs

The problem-mapping FGDs waere held in eight of the twelve villages previously visited in the problem-scoping process (for schedule, see Table 5-1, map:). Four fishing villages (Mekar Indah, Parak, Bontolebang, Harapan/Dodaiya) were excluded in this assessment since the three most important problems were not explicitly related to village fishery resources or fishing (for more on problem-scoping results, see Section 4.1). An FGD involving open-ended interviews was conducted with a group of cyanide fishers from Kahu-Kahu and fish vendors from the main fish market in Benteng Selatan in an impromptu manner since their participation was subject to their availability.

Table 5-1. Two rounds of problem-scoping FGDs were scheduled in each of the eight fishing villages. In each village, two FGDs were held for both of the participant groups.

No.	District / *Kecamatan*	Village / *Desa*	Participant group	Round One date	Round Two date
FGDs involving GMB:					
1	Bontoharu	Kahu-kahu	1	27/09/2015	24/01/2016
2	Bontoharu	Kahu-kahu	2	28/09/2015	24/01/2016
3	Bontoharu	Bontoborusu	1	29/09/2015	2/02/2016
4	Bontoharu	Bontoborusu	2	30/09/2015	25/02/2016
5	Bontomatene	Bungaiya	1	1/10/2015	26/01/2015
6	Bontomatene	Bungaiya	2	2/10/2015	27/01/2016
7	Bontomatene	Barat Lambongan	1	11/10/2015	24/01/2016
8	Bontomatene	Barat Lambongan	2	12/10/2015	25/01/2016
9	Bontosikuyu	Patikarya	1	13/10/2015	28/01/2016
10	Bontosikuyu	Patikarya	2	14/10/2015	29/01/2016
11	Bontoharu	Bontosunggu	1	15/10/2015	23/02/2016
12	Bontomanai	Barugaiya	1	17/10/2015	28/02/2016
13	Bontomanai	Barugaiya	2	19/10/2015	26/02/2016
14	Benteng	Benteng Utara	1	20/10/2015	27/02/2016
15	Benteng	Benteng Utara	2	21/10/2015	26/02/2016
FGDs involving open-ended interviews:					
1	Bontoharu	Kahu-kahu	Cyanide fishers	16/10/2015	
l2	Benteng	Benteng Selatan	Fish vendors	18/10/2015	

5.1.1.2 Participants of problem-mapping FGDs

Drawing from the stakeholders identified in problem scoping (Section 4.1.1.2) and after consultation with a local collaborator to help establish participant homogeneity (i.e., to minimise conflict due to participants' differing socioeconomic or sociocultural backgrounds (Krueger & Casey 2009)), two groups were defined by the team, mainly based on their role in village fishery. The groups are:

- FGD participant group 1: Women and men directly participating in fish harvesting and in utilising harvested fish for commercial or subsistence purposes.
- FGD participant group 2: Women and men indirectly affiliated with village fishing activities (e.g., the representative of the village's government office and cultural figures).

Based on the attendance lists (Appendix 8 &Appendix 9), 10 to 25 village residents were chosen as participants in the problem-mapping FGDs. Rounds 1 and 2 included a total of 243 and 230 people, respectively; and there were 33 people in the open-ended interviews. As shown in Figure 5-1 and Figure 5-2, both rounds of FGDs were largely attended by male participants, most of whom were fishers, followed by village administrative staff members and a mix of casual/freelance workers (Chart C in both figures). From the same figure, it can be seen that the females were mostly involved as village administrative staff, followed by fish traders, fisher's wives (some of whom also helped in the trade of fish and related commodities) and small household-scale business (Chart B in both figures). The interview-based FGD in Kahu-Kahu involved thirteen fishermen and four wives of fishermen; and sixteen fish vendors from Benteng Selatan fish market.

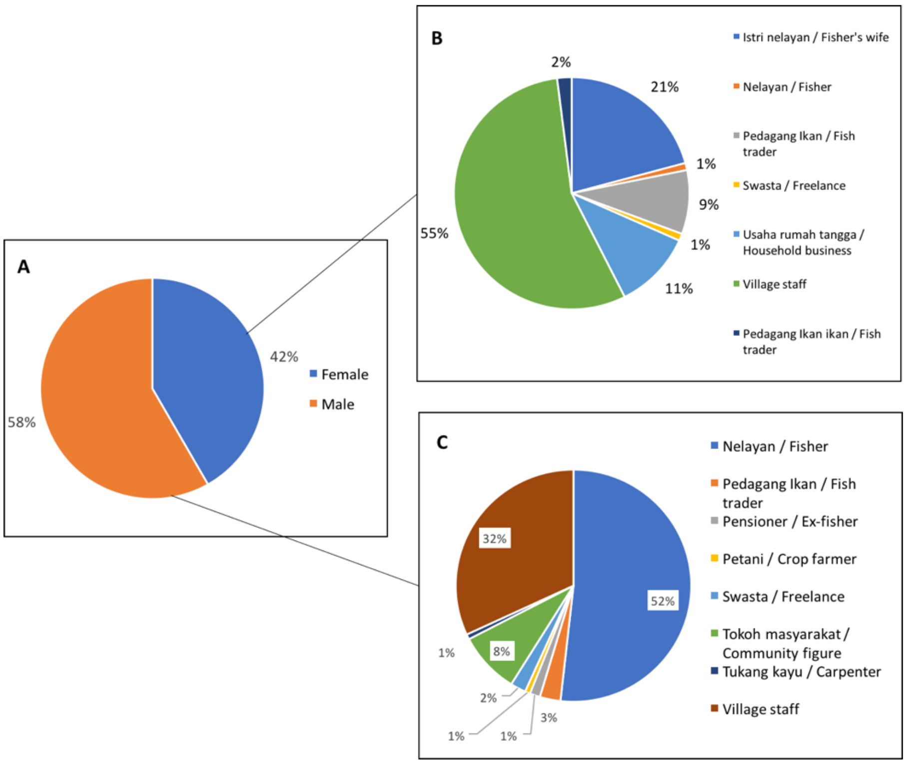

Figure 5-1. Pie charts showing the Round One problem-mapping FGD participant composition by gender (Chart A) and participant occupations from each gender group (Female: Chart B, Male: Chart C). Total participant count = 243. The charts summarise information from FGD participant attendance list data (see Appendix 8).

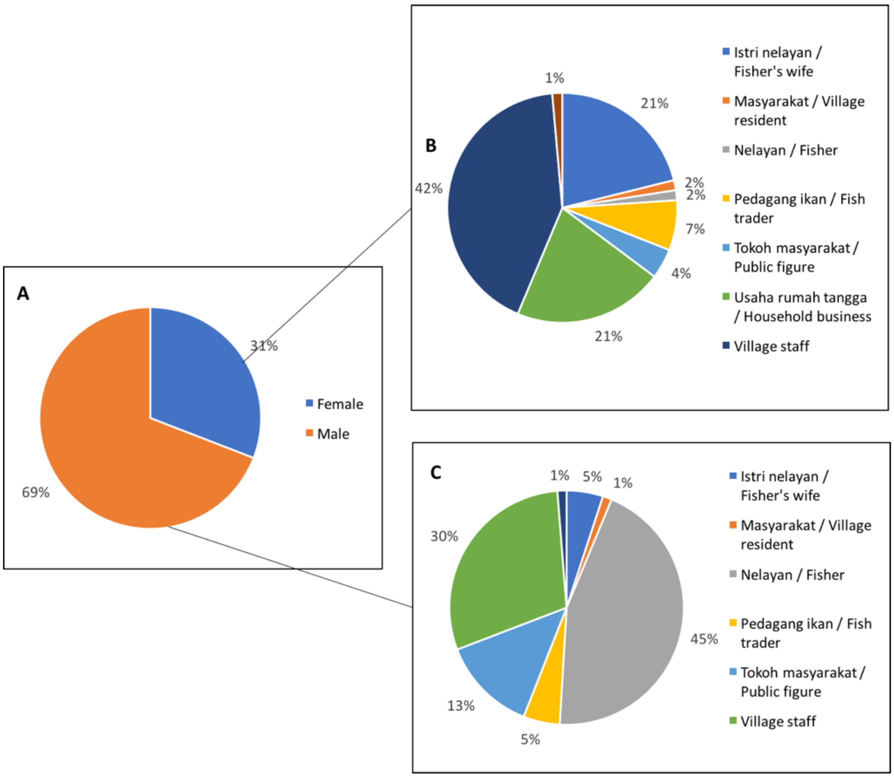

Figure 5-2. These 3 pie charts show the Round Two problem-mapping FGD participant composition by gender (Chart A) and participant occupations from each gender group (Female: Chart B, Male: Chart C). Total participant count = 230. The charts summarise information from FGD participant attendance list data (see Appendix 9).

5.1.1.3 SESAMME maps developed in two rounds of problem-mapping FGDs

In the FGDs of each problem mapping round, an iPad™ app called SESAMME (see Appendix 6) was used alongside the script to develop, record, or make revisions to digital rich pictures that were translatable into a causal loop diagram / CLD (more on CLD in Section 3.6.3).

In **Round One**, participants developed digital rich pictures (or, SESAMME maps) to record mental information elicited from participants using graphical elements (Figure 5-3) to help map the system associated to the topic problem, and, therefore, to examine the problem using an SES perspective (i.e., theoretical framework: Figure 2-3). The mental information collected was divided into several main groups of graphical elements, including (1) Activity, (2) Resource, (3) Pressure, (4) Decision, (5) Interaction, (6) Trend, and (7) State. Descriptions of the groups and their link to the theoretical framework are as follows:

1. The Activities group identifies livelihood activities related to the topic problem (i.e., livelihood configuration and the social and economic components, part of the aspects of the SLA framework: Figure 2-3).
2. The Resource group identifies natural resources in the SES (e.g., fish) that are affected by the livelihood activities (i.e., ecological assets of the livelihood, part of the aspects of the SLA framework: Figure 2-3).

3. The Pressure group identifies social or ecological variables that influence the past trends in Resources and Activities identified (i.e., population growth, commodity prices; part of the social/ecological history, trends, or shocks, part of the aspects of the SLA framework: Figure 2-3).
4. The Decision group identifies decisions that stakeholders could make to address problematic trends in Resources, Activities, or Pressures (i.e., policies, part of the aspects of the SLA framework: Figure 2-3).
5. The Interaction depicts the direct interactions between Resources, Activities, Pressures, and/or Decisions (i.e., interactions, part of the aspects of the SES framework: Figure 2-3).
6. The Trend depicts the past, expected future, or desired future trends of the Resource, Activity, or Pressure variables (i.e., dynamic patterns, part of the aspects of the conceptual framework: Figure 2-10).
7. The State indicates the current condition of the Resources (i.e., the state of the ecological asset of the livelihood, part of the aspects of the SLA framework: Figure 2-3).

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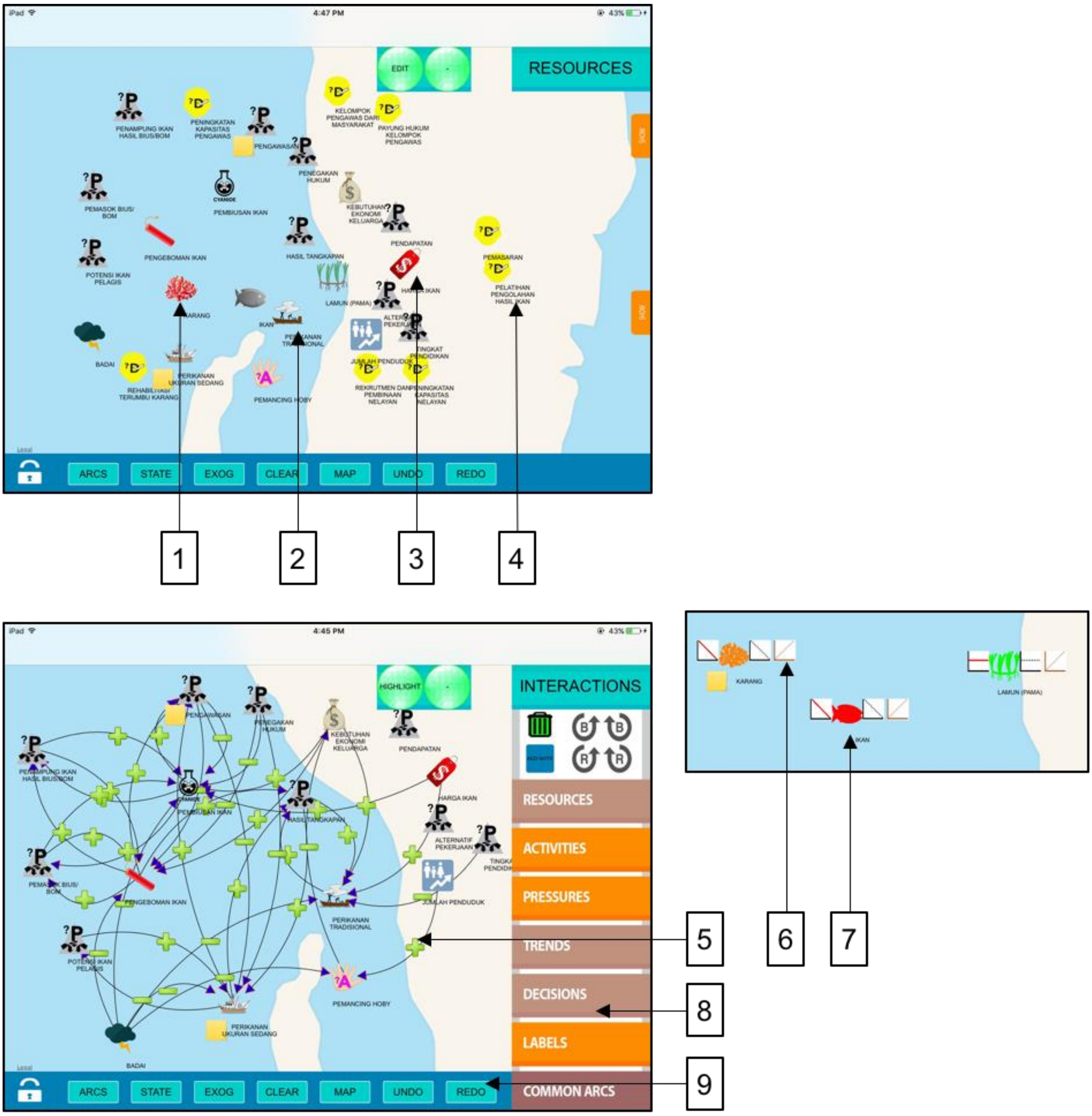

Figure 5-3. Screenshots taken from the iPad™ showing different graphical user interfaces (GUIs) in the SESAMME app that were displayed during FGDs to record different graphical elements depicting different mental information about Resource (1, *karang*/coral), Activity (2, *perikanan traditional*/traditional fishing), Pressure (3, *harga ikan*/fish price), Decision (4, *pelatihan*/trainings), Interaction (5, arrows with polarity symbol), Trend (6, trend lines in boxes of the past, expected future, and desired future from left to right), and State (7, red, orange, green icon colour fills using the 'STATE' button in bottom menu bar); indicating variables that are exogenously influencing by displaying a transparent icon (9, 'EXOG' button in bottom menu bar). The GUI also allows facilitators and participants to selectively show and hide elements (8, right menu bar), make editing (9, bottom menu bar).

After Round One, the SESAMME map elements were populated and counted by tabulating the information in the Excel ® software (Appendix 12). To maintain consistency, the variable icons (resource, activities, pressures, decisions) that were found to have unclear meaning were revisited by checking FGD written notes or audio records as necessary. Furthermore, variables that were found to have similarities in literal meaning were conservatively merged where necessary. Finally, all text information extracted from the rich pictures was converted into formal Bahasa Indonesian by the Indonesian team member and finally converted and proofread in formal English by the Australian team members. In this way, a list of variables was developed and used consistently in the analysis of results (Table 1, Appendix 12). After the element counts, the team extracted the most frequently mentioned map elements of all FGDs (excluding State and Trends) and used this information to develop a draft version of an 'integrated' CLD (hereafter referred to as **CLD 1**, for results, see Section 5.3.1) since each SESAMME map produced was essentially translatable to a CLD (Section 5.2.1.1).

Before **Round Two**, the SESAMME maps developed after each of the Round One FGDs were compared with the CLD 1 and then marked for any bimodal occurrence. The marking was done directly in the app (Figure 5-4) by identifying map elements that (1) occurred differently to CLD 1, or (2) element(s) of CLD 1 that was not identified in the SESAMME map.

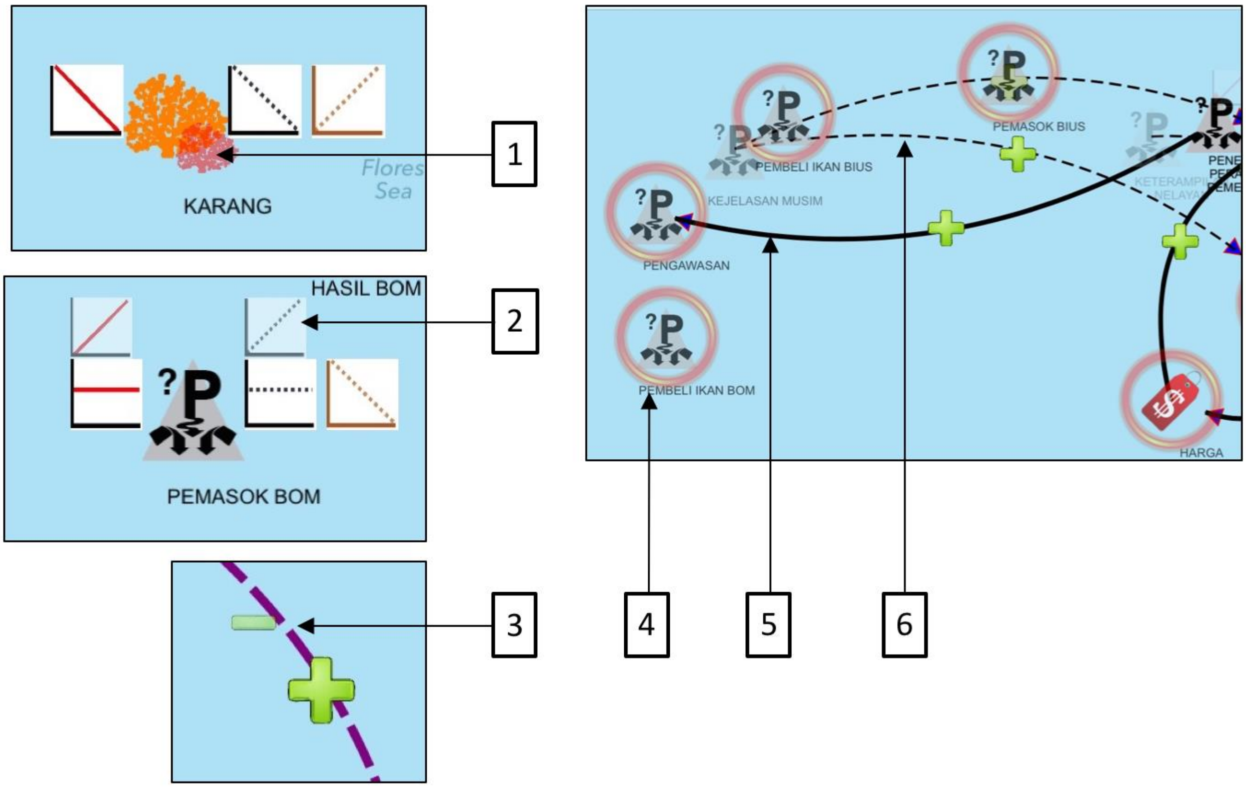

Figure 5-4. A partial screenshot of the ‘review mode’ GUI in the SESAMME app that was displayed during marking, displaying, and editing of SESAMME map elements with bimodal occurrence in the Round Two FGDs. When reviewing bimodalities, map elements with the highest occurrence from all round 1 FGDs were introduced to the participant using watermarks for resource states, perceived trends, and polarities. And variables were differentiated using: watermarks (no.s 1, 2, 3, and 4, respectively); a bold arrow line for interactions that participants did not identify (no. 5); and a dashed arrow line for interactions that were identified only by the participants. Participants could then collectively decide which map element version would best reflect their perception.

During each of the Round Two FGDs, the identified bimodal occurrences were presented back to the participants to compare between elements that they previously agreed on in Round One and the elements in CLD 1 that, again, represent the dominant perception of the participants in all FGDs. This was done to allow (1) ‘integration’ to combine ideas from several rich pictures and (2) ‘triangulation’ to see where the different rich pictures confirm each other.

During the review of the bimodal elements, in each Round Two FGD, facilitators were able to display and toggle directly in the SESAMME app between the graphical elements recorded in Round One (as the first mode) and from CLD 1 (as the second mode). This was done when the facilitator asked the associated participant group for their agreement between the two modes of the same graphical elements (Figure 5-4) , script: Appendix 5). As indicated in Figure 5-4 , when comparing the modes, the first mode versions of the resource variable state were indicated by the smaller icons (no. 1), and smaller transparent icons indicated the trends (no. 2) and polarities (no.

3). Furthermore, the second mode versions of variables that were new or being introduced (not recorded in the first mode) were displayed using icons in the red circle (no. 4), and a bold arrow line for the interaction arrow (no. 5). Interactions that did not exist in the second mode version were displayed as arrows with a dashed line (no. 6). Round Two finished when all bimodal occurrences of the SESAMME map elements were reviewed/justified for participant agreement.

After all of the Round Two of problem-mapping FGDs were conducted, the mental information from the revised rich picture from each of the group of each FGD was extracted, populated, and counted in a similar manner to that of Round One. After the element counts, the team extracted the most frequently mentioned map elements of all FGDs (excluding State and Trends) and used it to develop a 'participant-justified' integrated CLD (hereafter referred to as **CLD 2**, for results: Section 5.3.2).

5.1.2 Problem-mapping FGD outputs

Overall, 15 problem-mapping FGDs (schedule: Table 5-1) were able to produce SESAMME maps in both rounds one and two (maps: Appendix 11). A total of 282 graphical elements were recorded throughout the series of Round One FGDs. After the second round of FGDs, it was agreed that 265 element records from Round One should be added, and it was agreed that 46 records be deleted, resulting in an agreed (approximate) 92% of the information from Round One being preserved or added in Round Two FGDs (see 'Grand Total' in Table 1, Appendix 12). All FGDs were able to elicit variables representing the graphical elements group (Resource, Activity, Pressure, Decision, State, Trends, and Interaction), which are presented in the following sections.

5.1.2.1 Variables related to the topic problem

From all SESAMME maps developed in the Round One of the problem-mapping FGDs, a total of 94 variable names were defined (for the list of variables, see Table 1, Appendix 12) after omitting and/or merging 18 of the 112 variables identified from the recorded graphical elements (Resource, Activity, Pressure, and Decision variables) (for merged/omitted variables, see Table 10 , Appendix 12). These variables were identified by the team members by visually checking each of the variable icons recorded in the SESAMME maps and listing the names of the variables. Where necessary, the merging and omission of variables and the English rewording of the variable names were determined based on a consensus reached by the modelling team and the local collaborator (Section 3.5). The following bar charts describe the names of variables for each group of variables, and the number of the Round One and two FGDs in which the variables were identified (from Figure 5-5 to Figure 5-10).

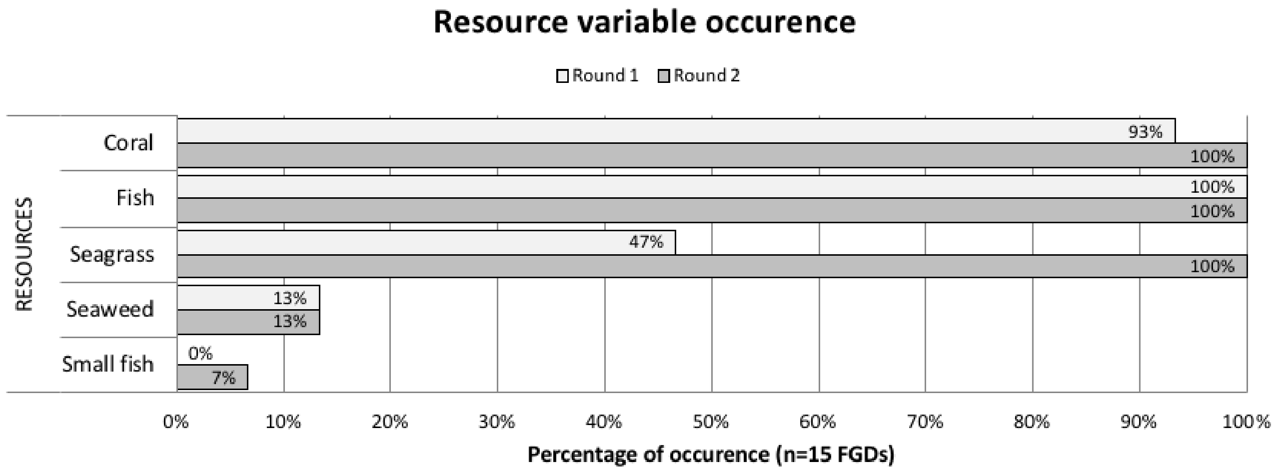

Figure 5-5. Bar chart showing the percentage of occurrence (X-axis) of variable names recorded under the Resource group (Y-axis) based on the associated number of FGDs (total FGDs = 15) where the variable is agreed by participants to be recorded in the rich pictures.

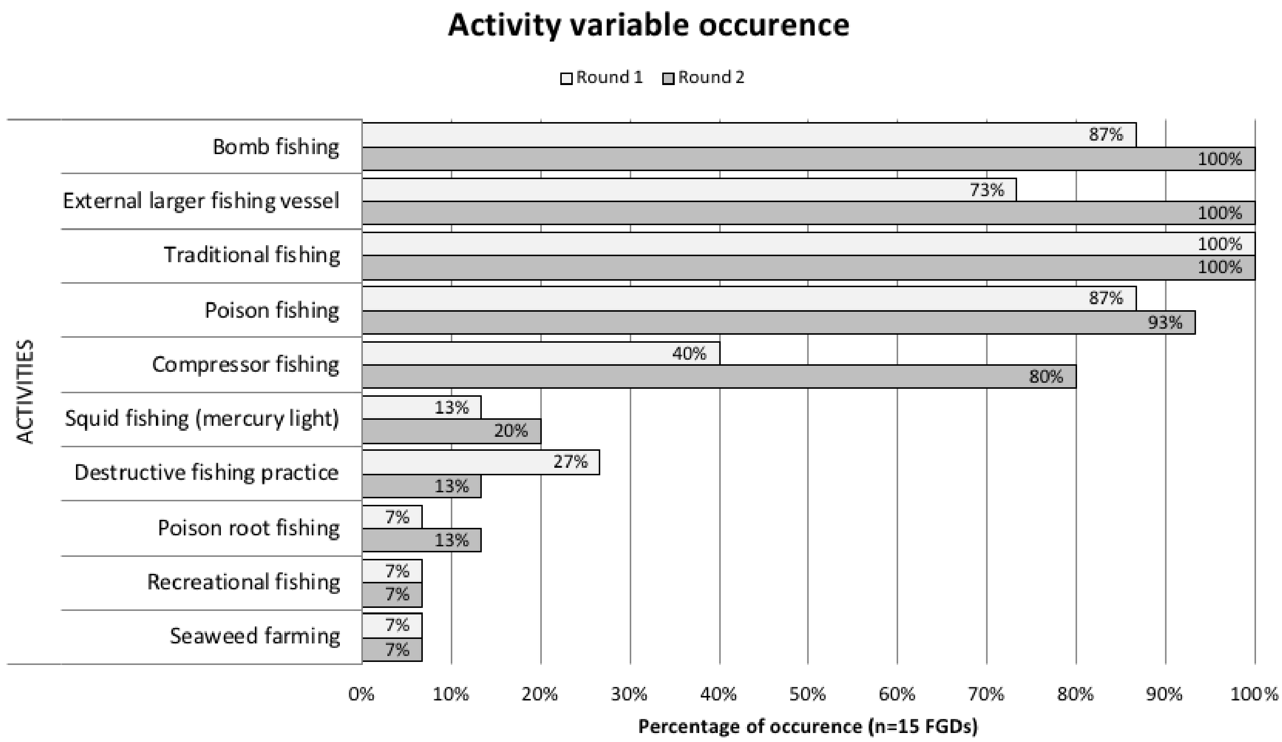

Figure 5-6. Bar chart showing the percentage of occurrence (X-axis) of variable names recorded under the Activity group (Y-axis) based on the associated number of FGDs (total FGDs = 15) where the variable is agreed by participants to be recorded in the rich pictures.

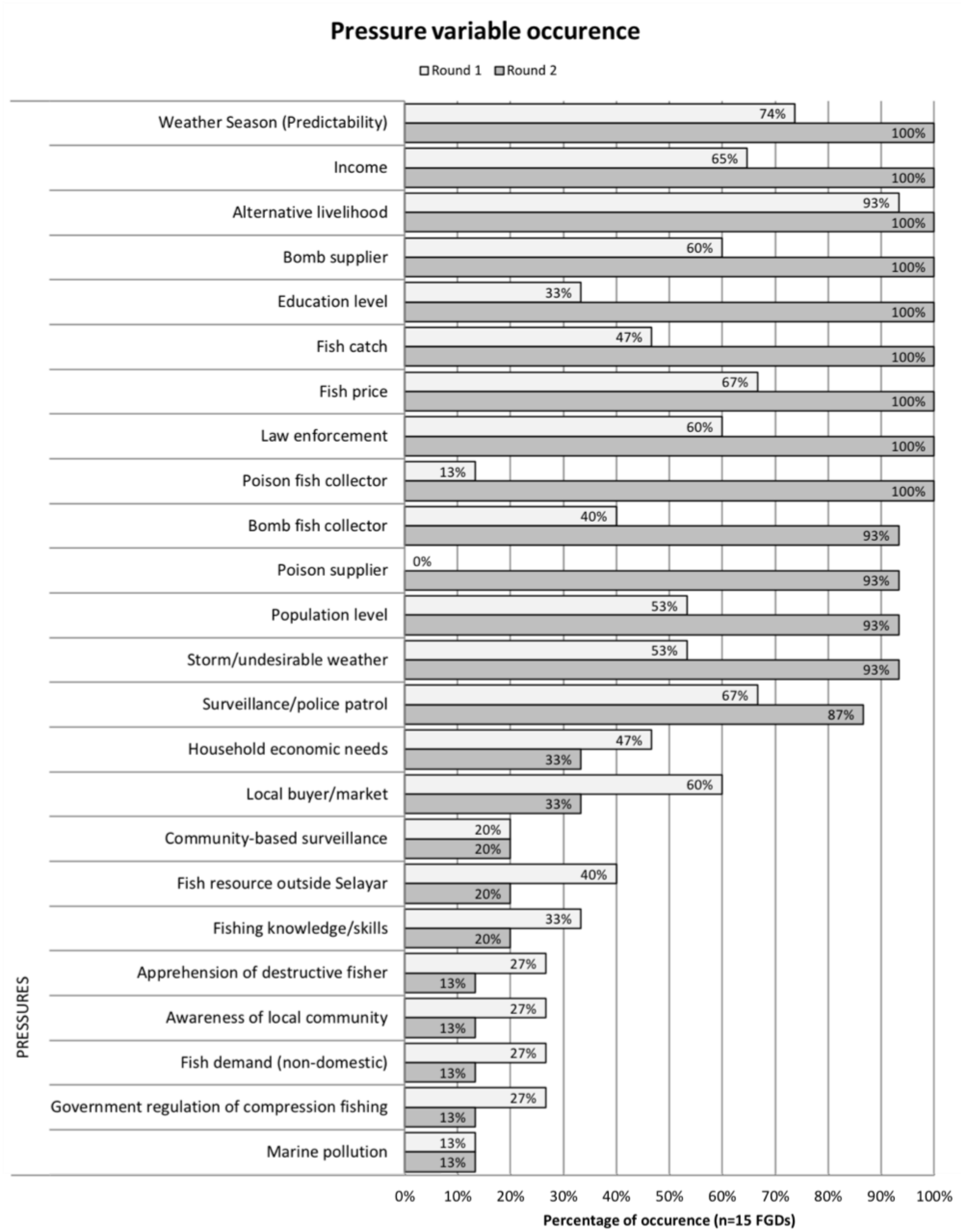

Figure 5-7. Bar chart showing the percentage of occurrence (X-axis) of variable names recorded under the Pressure group (Y-axis) based on the associated number of FGDs (total FGDs = 15) where the variable is agreed by participants to be recorded in the rich pictures. This chart continues to Figure 5-8

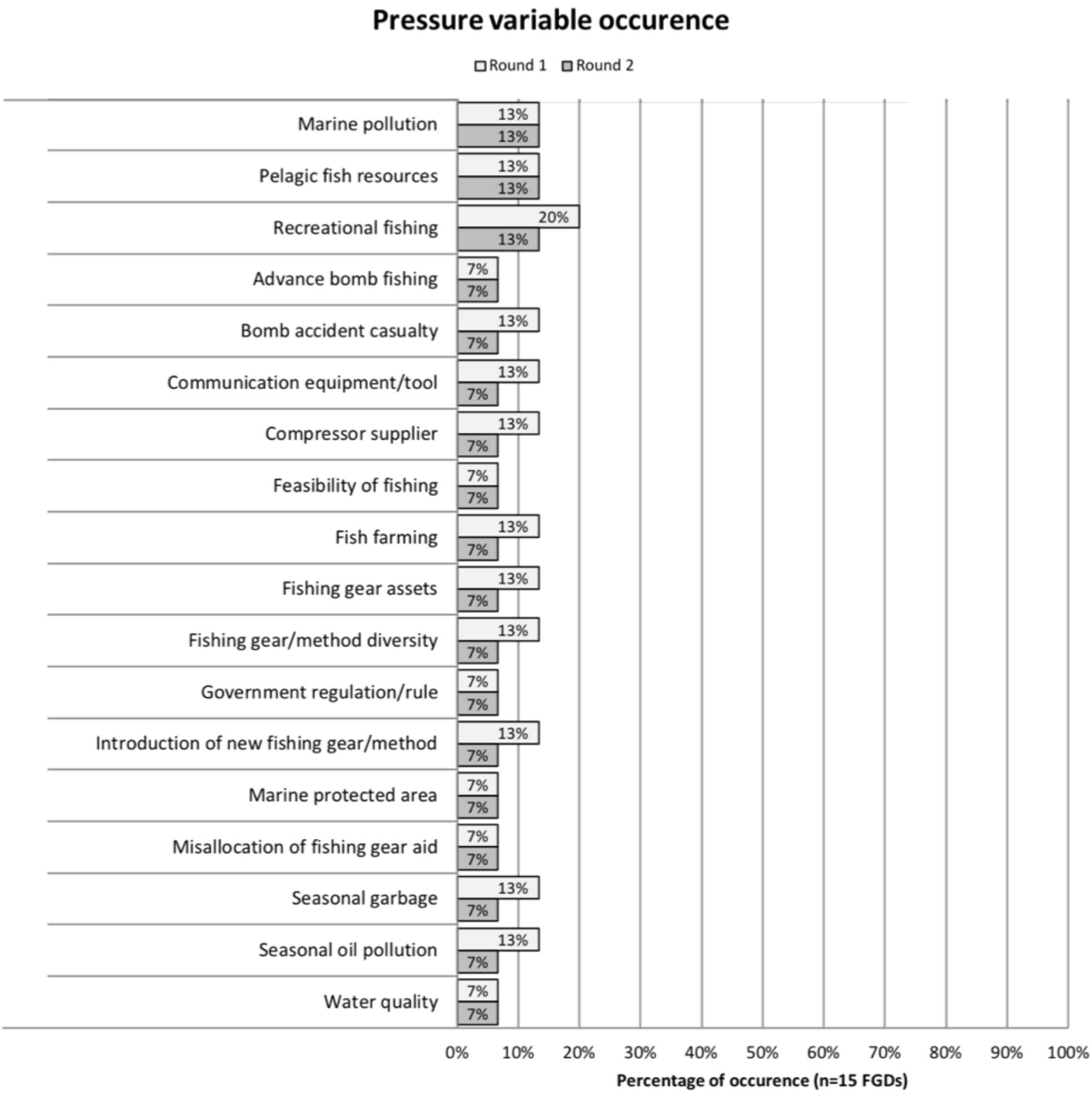

Figure 5-8. Bar chart (continued) showing the percentage of occurrence (X-axis) of variable names recorded under the Pressure group (Y-axis) based on the associated number of FGDs (total FGDs = 15) where the variable is agreed by participants to be recorded in the rich pictures. This chart is the bottom part of Figure 5-7.

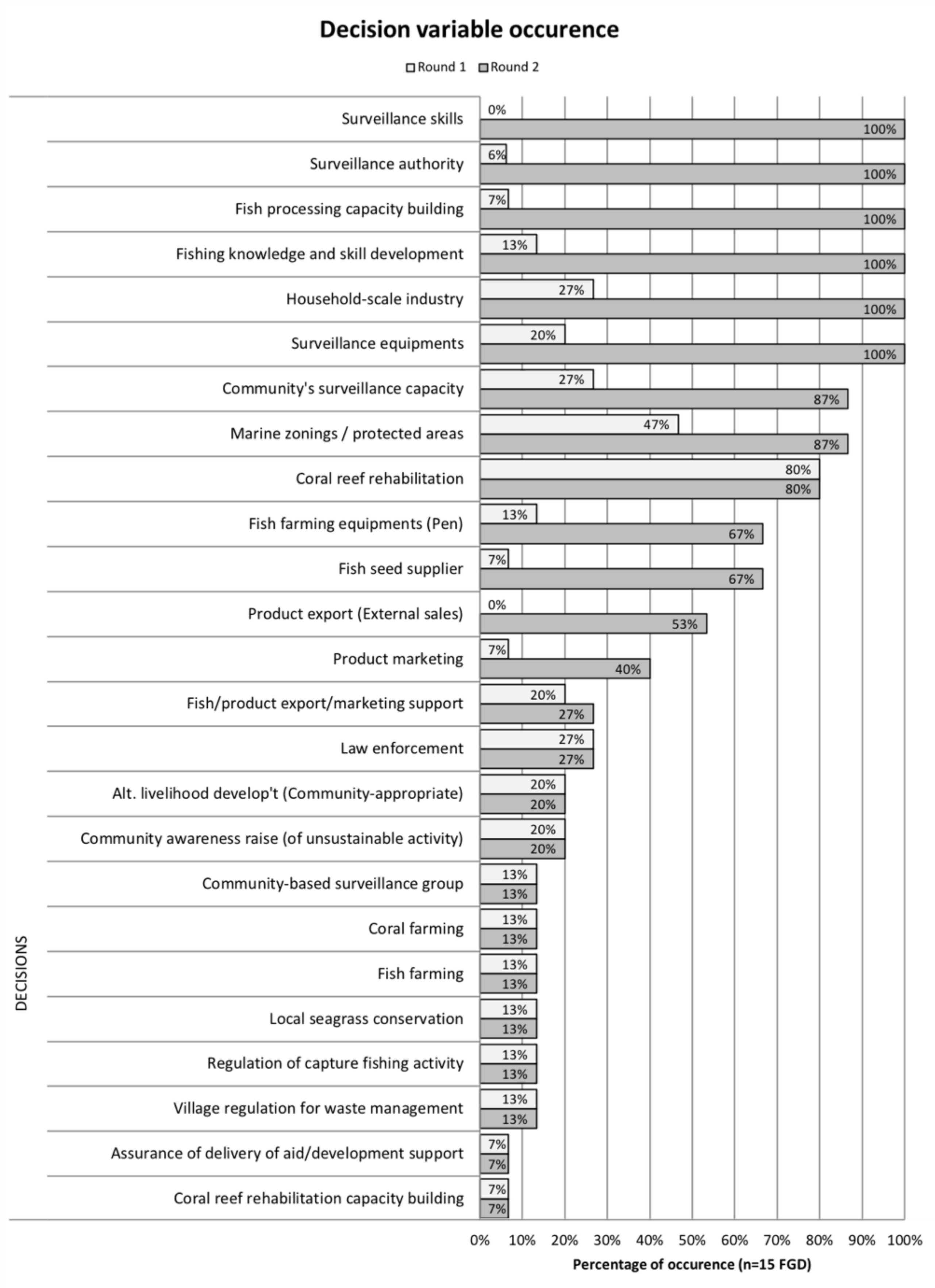

Figure 5-9. Bar chart showing the percentage of occurrence (X-axis) of variable names recorded under the Decision group (Y-axis) based on the associated number of FGDs (total FGDs = 15) where the variable is agreed by participants to be recorded in the rich pictures. This chart continues to Figure 5-10.

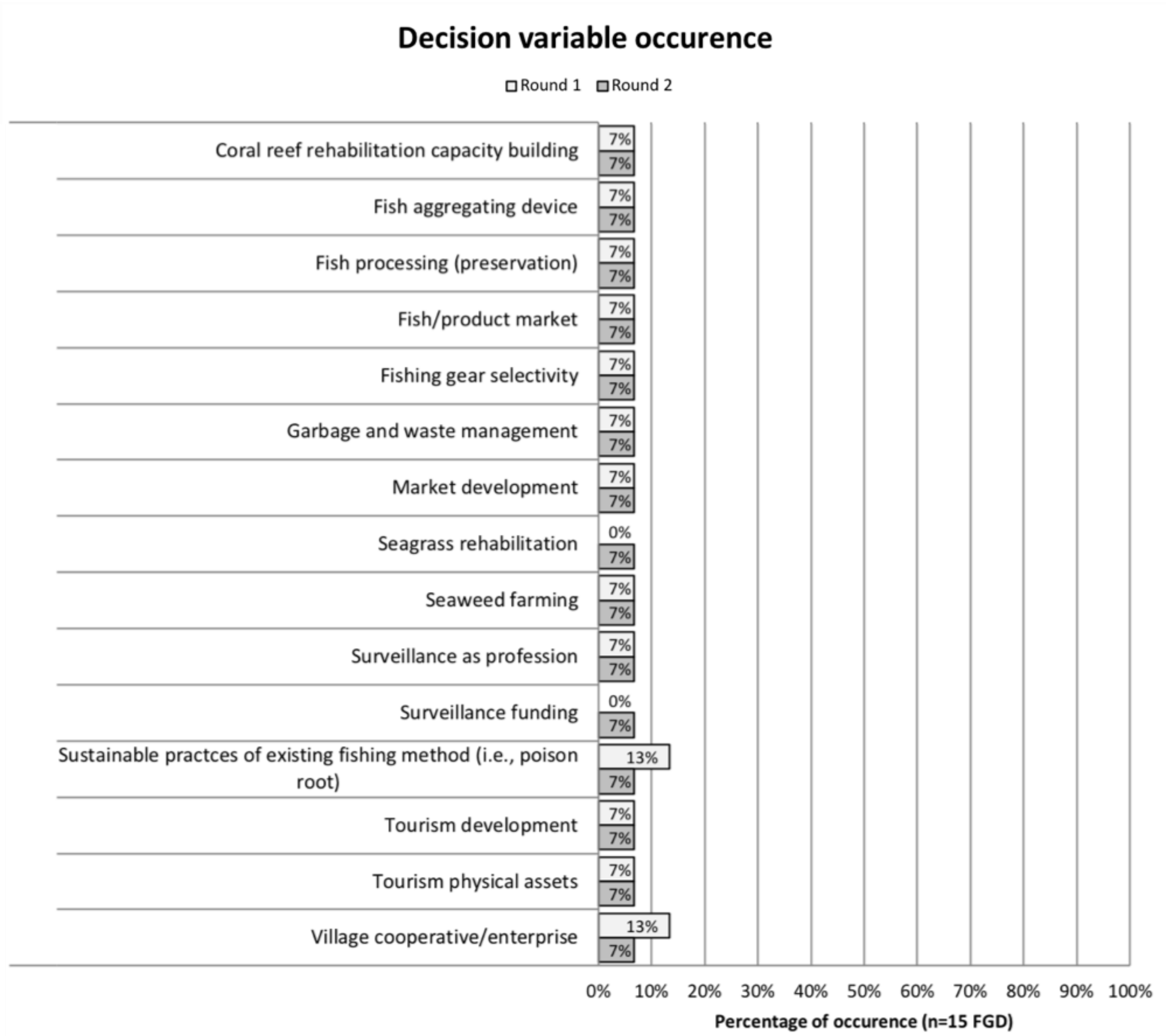

Figure 5-10. Bar chart (continued) showing the percentage of occurrence (X-axis) of variable names recorded under the Decision group (Y-axis) based on the associated number of FGDs (total FGDs = 15) where the variable is agreed by participants to be recorded in the rich pictures. This chart is the bottom part of Figure 5-9.

5.1.2.2 Resource variable states related to the topic problem

Coral, Fish, Seagrass, and Seaweed were the variables that received responses regarding the perceived current/recent state of the resource, which was agreed on in both rounds one and two (no revision). The first three variables were justified in all fifteen FGDs in Round Two, with the exception of Seaweed, for which only two FGDs described and agree on a perceived state. The state of seaweed was only able to be defined by both participant groups in Bungaiya Village since the village is the only study site where community members work in seaweed farming in addition to traditional fishing. As shown in the pie charts below (data: Table 2 in Appendix 12), 'yellow' was the majority of the state of the resource variables; which represents an 'average' condition accross three quality rankings from ‘bad’ to ‘good’ (red, yellow, green) in the inquiry (for the scripts: Appendix 3 & Appendix 5).

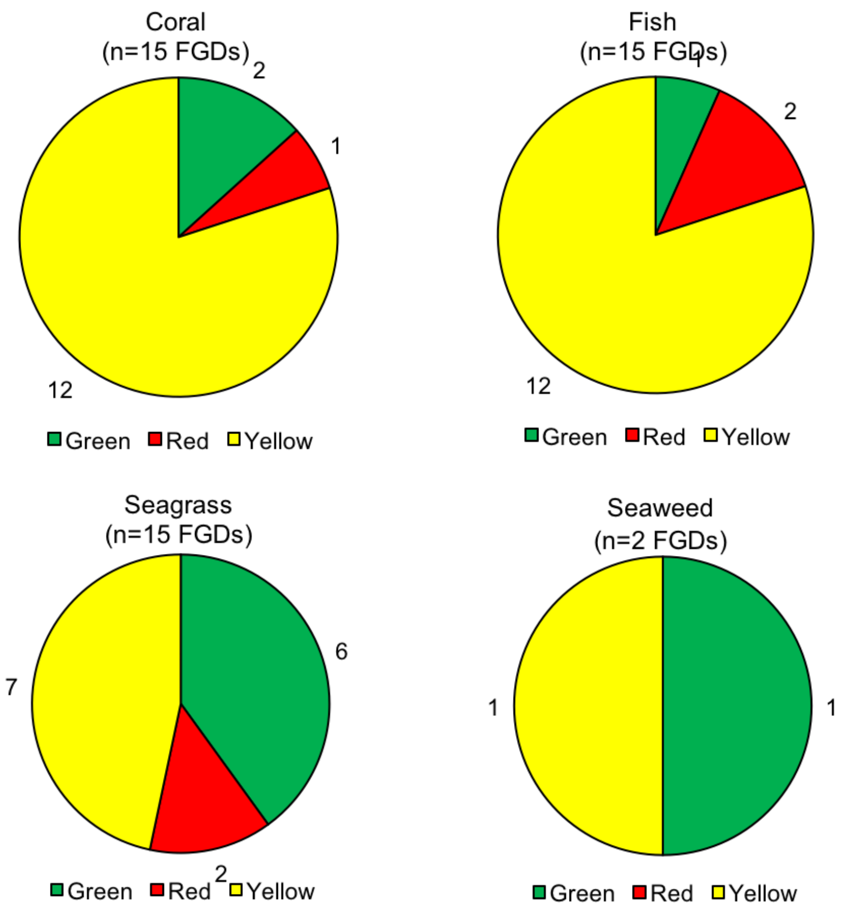

Figure 5-11. Pie chart showing the various perceptions of the current/recent state of each of the identified resource variables and the number of FGDs where participants were able to describe it.

5.1.2.3 Trends of the variables related to the topic problem

From all the trend icons extracted from the problem-mapping FGDs, six types of trend metaphors were identified (see Figure 5-12) and were used to describe the distant past, and estimated and desired future conditions (within five to ten years period, see FGD script in Appendix 3) of the Resource, Activity, and Pressure variable groups. The perceived trends were (1) ‘same/unchanging’, (2) ‘stable then sharp decline, (3) ‘gradually increasing’, (4) ‘gradually decreasing’, (5) ‘sharp increase then levelling off’, and (6) ‘sharp decline and levelling off’.

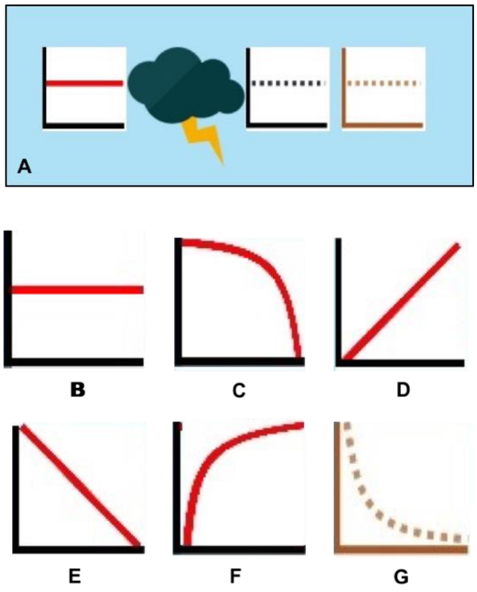

Figure 5-12. The picture elements that are used to represent various trends of the Resource, Activity, and Pressure variables. During the problem-mapping FGDs, participants were asked to identify the type of trends of each of the resource, activity, and pressure variables for the (1) past, (2) estimated future, and (3) desired future conditions (see A, red line, black dotted line, brown dotted line, respectively) and to select the appropriate trend icons. From all icons recorded, six types of trends were identified, namely: 'same/unchanging' (B), 'stable followed with sharp decline' (C), 'gradually increasing' (D), 'gradually decreasing' (E), 'sharp increase then levelling off' (F), and 'sharp decline and levelling off' (G).

After summarising the trends from each of the Round Two FGDs (where participant compare the trends that they agreed on in the Round One FGD, with trends that had the highest occurrence in all of the Round One FGDs), more variables were associated with a 'dominant' trend type, such as those that were recorded in more than ten FGDs in Round Two, (70%, n = 15 FGDs, Table 5-2). However, bimodal responses were also recorded for most of the variables under all trend type groups (past, expected future, and desired future trend), whereby variables were found to be associated with two or three different types of trends (Table 5-3). The less dominant types of trends of each variable can be found in Table 3a of Appendix 12.

Table 5-2. Trend type with the highest number of FGDs where the trend was recorded for each variable. Trend type code description related to Figure 5-12: -- (Same/unchanging), --\ (Stable followed with sharp decline), / (Gradually increasing) \ (Gradually decreasing), /-- (Sharp increase then levelling off), L (Sharp decline then levelling off)

	Past trend		Estimated future trend		Desired future trend	
Variable Group Variable name	Does the variable receive a dominant (>70% of total FGDS) trend?	Trend type with the highest number of FGDs where the trend was recorded	Does the variable receive a dominant (>70% of total FGDS) trend?	Trend type with the highest number of FGDs where the trend was recorded	Does the variable receive a dominant (>70% of total FGDS) trend?	Trend type with the highest number of FGDs where the trend was recorded
Resources:						
Coral	**Yes**	\		\	**Yes**	/
Fish	**Yes**	\		\	**Yes**	/
Seagrass		\		--	**Yes**	/
Seaweed		--	**Yes**	--	**Yes**	/
Activities:						
Bomb fishing	**Yes**	\	**Yes**	\	**Yes**	\
Compressor fishing		--\	**Yes**	/	**Yes**	\
Destructive fishing practice	**Yes**	--		--	**Yes**	\
External fishing encroachment (Larger vessel)		/	**Yes**	/	**Yes**	\
Poison fishing	**Yes**	/	**Yes**	--	**Yes**	\
Poison root fishing		\		--		\
Recreational fishing	**Yes**	/	**Yes**	/	**Yes**	--
Seaweed farming	**Yes**	L	**Yes**	\	**Yes**	--\
Squid fishing (mercury light)		/	**Yes**	/		--
Traditional fishing	**Yes**	/	**Yes**	/	**Yes**	\
Pressures:						
Advanced bomb fishing	**Yes**	/	**Yes**	/	**Yes**	--
Alternative livelihood	**Yes**	/	**Yes**	/	**Yes**	--
Apprehension of destructive fisher	**Yes**	\	**Yes**	\	**Yes**	--\
Awareness of local community	**Yes**	\	**Yes**	\	**Yes**	--\
Bomb accident casualty	**Yes**	\	**Yes**	\	**Yes**	--\
Bomb fish collector	**Yes**	--	**Yes**	\	**Yes**	\
Bomb supplier	**Yes**	--	**Yes**	--	**Yes**	\
Communication equipment/tool	**Yes**	/	**Yes**	/	**Yes**	--
Community-based surveillance	**Yes**	/	**Yes**	--	**Yes**	\
Compressor supplier	**Yes**	/	**Yes**	/	**Yes**	--
Education level	**Yes**	/	**Yes**	/	**Yes**	--
Feasibility of fishing	**Yes**	--	**Yes**	--	**Yes**	\
Fish catch		\		\	**Yes**	\
Fish demand (non-domestic)	**Yes**	/	**Yes**	/	**Yes**	--
Fish farming	**Yes**	--	**Yes**	--	**Yes**	\
Fish price	**Yes**	/	**Yes**	/	**Yes**	\
Fish resource outside Selayar	**Yes**	\	**Yes**	\	**Yes**	--\

	Past trend		Estimated future trend		Desired future trend	
Variable Group Variable name	Does the variable receive a dominant (>70% of total FGDS) trend?	Trend type with the highest number of FGDs where the trend was recorded	Does the variable receive a dominant (>70% of total FGDS) trend?	Trend type with the highest number of FGDs where the trend was recorded	Does the variable receive a dominant (>70% of total FGDS) trend?	Trend type with the highest number of FGDs where the trend was recorded
Fishing gear assets	**Yes**	/	**Yes**	/	**Yes**	--
Fishing gear/method diversity	**Yes**	/	**Yes**	/	**Yes**	--
Fishing knowledge/skills		/		--	**Yes**	\
Government regulation of compression fishing		--		--\		\
Government regulation/rule	**Yes**	/	**Yes**	/	**Yes**	--
Household economic needs	**Yes**	/	**Yes**	/		\
Income	**Yes**	/	**Yes**	/	**Yes**	\
Introduction of new fishing gear/method	**Yes**	/	**Yes**	--	**Yes**	\
Law enforcement		\	**Yes**	--	**Yes**	\
Local buyer/market	**Yes**	--		/	**Yes**	\
Marine pollution	**Yes**	--	**Yes**	--	**Yes**	\
Marine protected area	**Yes**	/	**Yes**	/	**Yes**	--
Misallocation of fishing gear aid	**Yes**	/	**Yes**	/	**Yes**	--
Pelagic fish resources		/	**Yes**	\	**Yes**	--\
Poison fish collector	**Yes**	--	**Yes**	--	**Yes**	\
Poison supplier	**Yes**	/	**Yes**	/	**Yes**	\
Population level	**Yes**	/	**Yes**	/	**Yes**	--
Recreational fishing		--		/	**Yes**	\
Seasonal garbage	**Yes**	/	**Yes**	/	**Yes**	--
Seasonal oil pollution	**Yes**	--	**Yes**	--	**Yes**	\
Storm/undesirable weather		--	**Yes**	--	**Yes**	\
Surveillance/police patrol		/		--	**Yes**	\
Water quality	**Yes**	\	**Yes**	\	**Yes**	--\
Weather season (predictability)	**Yes**	\	**Yes**	--	**Yes**	\

Table 5-3. The number of trend types recorded for each variable under each trend perception group.

	Past trend		Estimated future trend		Desired future trend	
Variable Group Variable name	Count of types of trends recorded for the variable	Bimodal response?	Count of types of trends recorded for the variable	Bimodal response?	Count of types of trends recorded for the variable	Bimodal response?
Resources:						
Coral	3	Yes	3	Yes	1	

	Past trend		Estimated future trend		Desired future trend	
Variable Group Variable name	Count of types of trends recorded for the variable	Bimodal response?	Count of types of trends recorded for the variable	Bimodal response?	Count of types of trends recorded for the variable	Bimodal response?
Fish	2	Yes	2	Yes	1	
Seagrass	2	Yes	3	Yes	1	
Seaweed	2	Yes	1		1	
Activities:						
Bomb fishing	2	Yes	1		3	Yes
Compressor fishing	3	Yes	2	Yes	2	Yes
Destructive fishing practice	1		2	Yes	1	
External fishing encroachment (Larger vessel)	3	Yes	3	Yes	2	Yes
Poison fishing	3	Yes	3	Yes	2	Yes
Poison root fishing	1		1		1	
Recreational fishing	1		1		1	
Seaweed farming	1		1		1	
Squid fishing (mercury light)	2	Yes	1	Yes	2	Yes
Traditional fishing	2	Yes	2	Yes	3	Yes
Pressures:						
Advanced bomb fishing	1		1		1	
Alternative livelihood	1		1		1	
Apprehension of destructive fisher	1		1		1	
Awareness of local community	1		1		1	
Bomb accident casualty	1		1		1	
Bomb fish collector	1		3	Yes	1	
Bomb supplier	3	Yes	2	Yes	1	
Communication equipment/tool	1		1		1	
Community-based surveillance	1		1		1	
Compressor supplier	1		1		1	
Education level	1		1		1	
Feasibility of fishing	1		1		1	
Fish catch	2	Yes	2	Yes	1	
Fish demand (non-domestic)	1		1		1	
Fish farming	1		1		1	
Fish price	2	Yes	2	Yes	3	Yes
Fish resource outside Selayar	1		1		1	
Fishing gear assets	1		1		1	
Fishing gear/method diversity	1		1		1	
Fishing knowledge/skills	2	Yes	2	Yes	1	
Government regulation of compression fishing	2	Yes	2	Yes	2	Yes
Government regulation/rule	1		1		1	
Household economic needs	1		1		2	Yes
Income	3	Yes	3	Yes	3	Yes

	Past trend		Estimated future trend		Desired future trend	
Variable Group Variable name	Count of types of trends recorded for the variable	Bimodal response?	Count of types of trends recorded for the variable	Bimodal response?	Count of types of trends recorded for the variable	Bimodal response?
Introduction of new fishing gear/method	1		1		1	
Law enforcement	3	Yes	2	Yes	1	
Local buyer/market	2	Yes	3	Yes	2	Yes
Marine pollution	1		1		1	
Marine protected area	1		1		1	
Misallocation of fishing gear aid	1		1		1	
Pelagic fish resources	2	Yes	1		1	
Poison fish collector	1		1		1	
Poison supplier	2	Yes	2	Yes	1	
Population level	1		2	Yes	2	Yes
Recreational fishing	2	Yes	1		1	
Seasonal garbage	1		2	Yes	1	
Seasonal oil pollution	1		1		1	
Storm/undesirable weather	2	Yes	1		2	Yes
Surveillance/police patrol	3	Yes	1		1	
Water quality	1		3	Yes	1	
Weather season (predictability)	2	Yes	1		1	

5.1.2.4 Interactions between variables

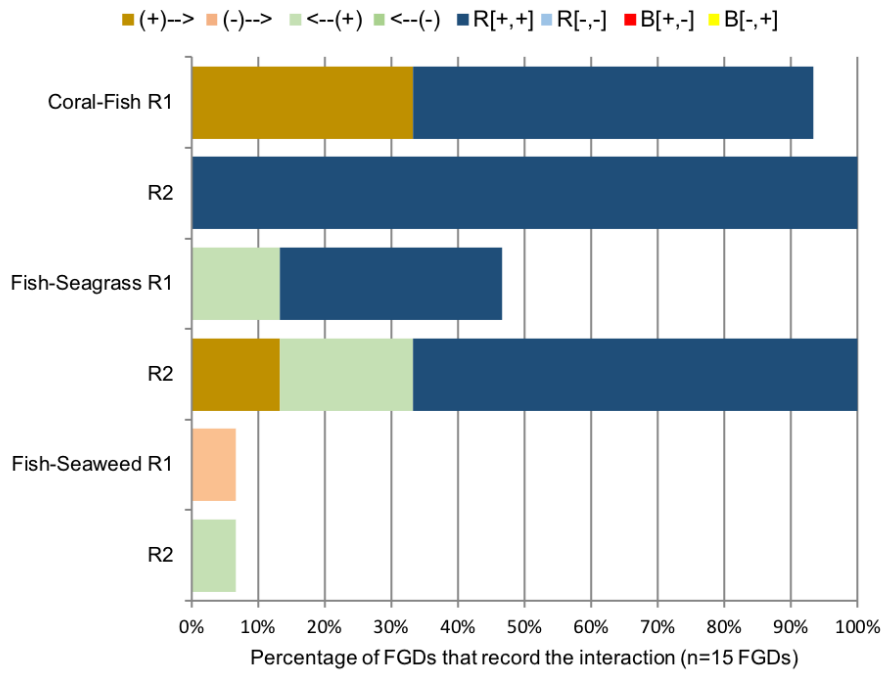

Figure 5-13. Stacked bar chart showing the composition of interactions between Resource variables, each for the Round One and Round Two problem mapping FGDs (Y axis) based on the number of FGDs where the variable interaction is recorded (X axis). (+) = + polarity, (-) = - polarity, --> = interaction from variable in the left to the right, <-- = interaction from variable in the left to the right, R[+,+] = reinforcing loop of two + interactions, R[-,-] = reinforcing loop of two – interactions, B[+,-] / B[-,+] = balancing loop.

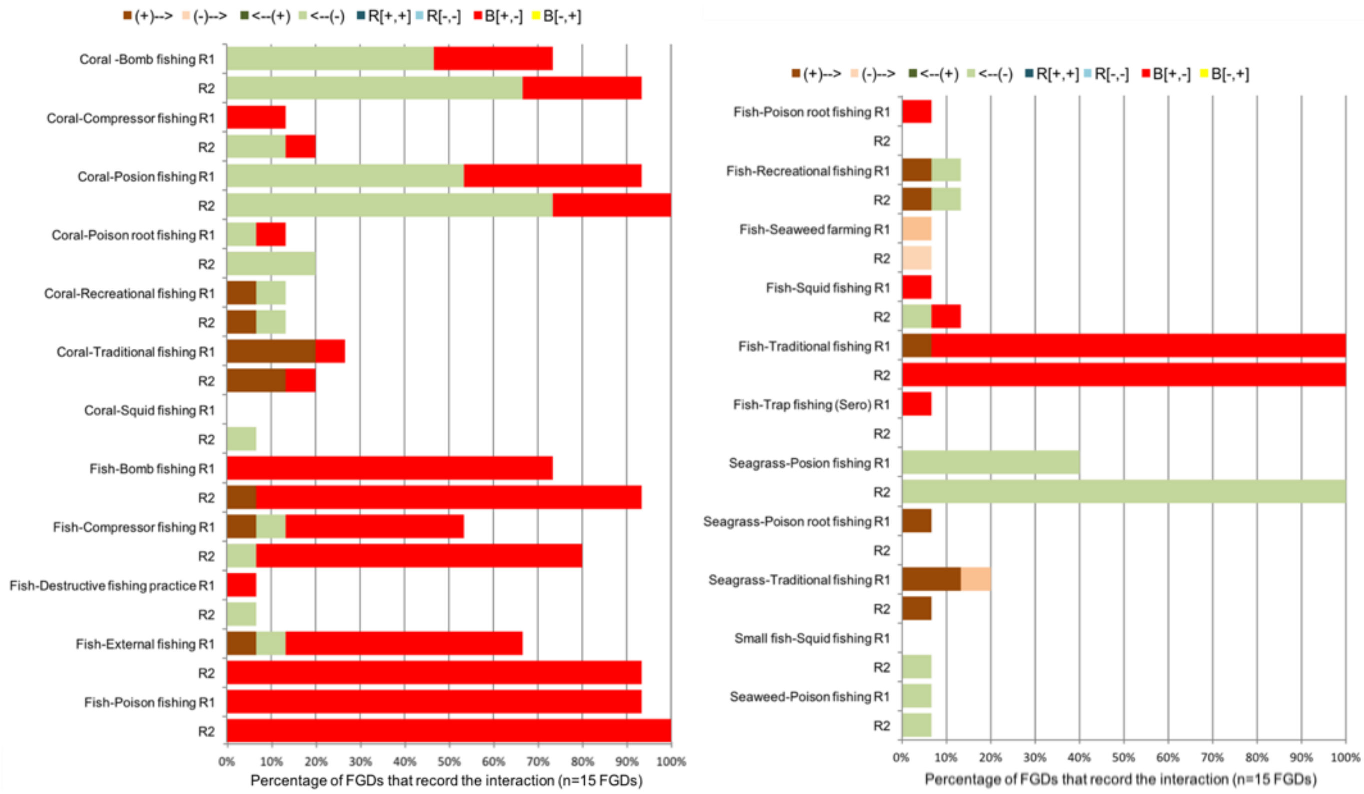

Figure 5-14. Stacked bar chart showing the composition of interactions between Resource and Activity variables (*Variable A-Variable B*, Y Axis), for both the Round One and Round Two problem-mapping FGDs (*R1* & *R2*, Y-axis) based on the number of FGDs where the variable interaction was recorded (X-axis). See caption of Figure 5-13 for bar colour code description.

Figure 5-15. Stacked bar chart showing the composition of interactions between Pressure and Activity variables (*Variable A-Variable B*, Y Axis), for both the Round One and Round Two problem-mapping FGDs (*R1* & *R2*, Y-axis) based on the number of FGDs where the variable interaction was recorded (X-axis). See caption of Figure 5-13 for bar colour code description.

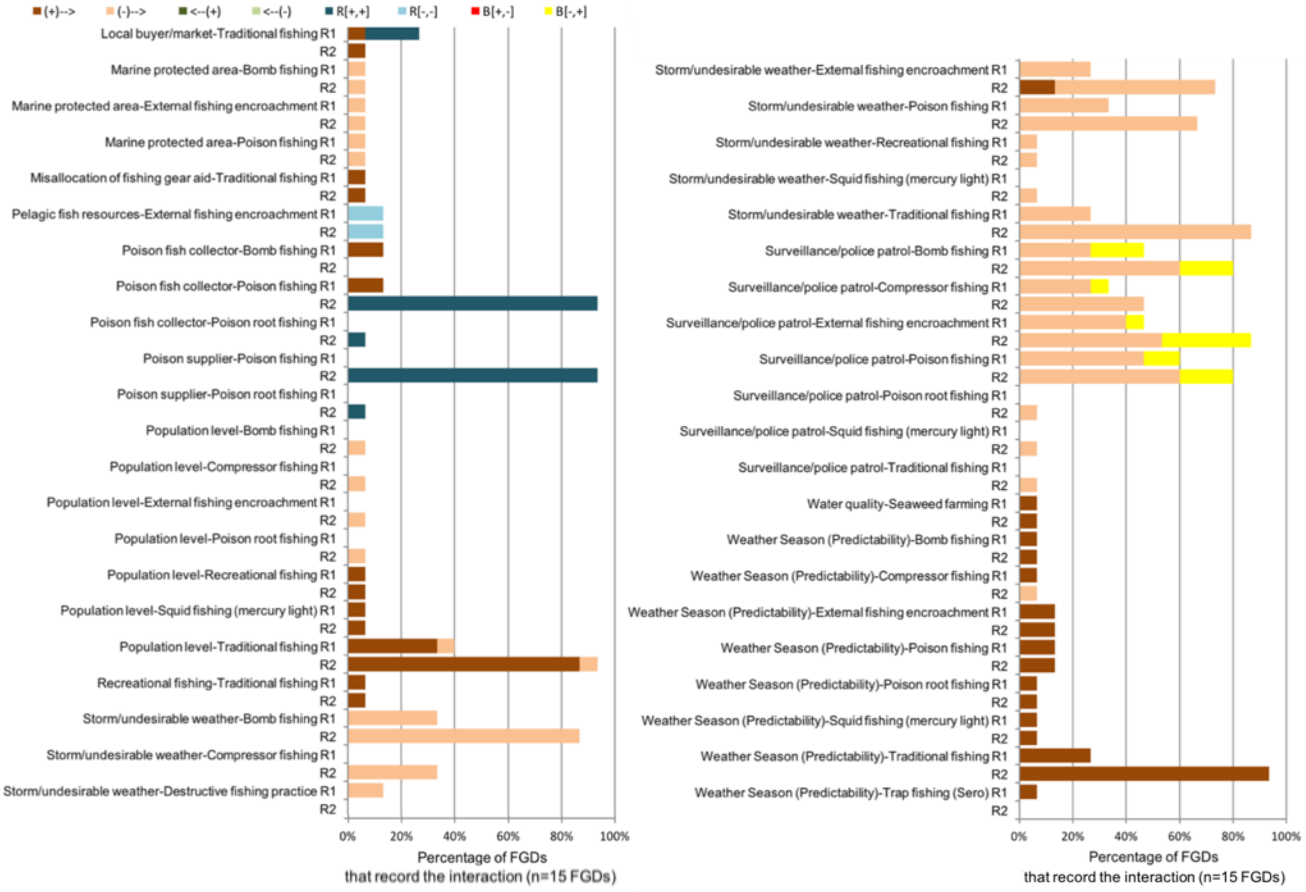

Figure 5-16. Stacked bar chart (continued from Figure 5-15) showing the composition of interactions between Pressure and Activity variables (*Variable A-Variable B*, Y Axis), for both the Round One and Round Two problem-mapping FGDs (*R1* & *R2*, Y-axis) based on the number of FGDs where the variable interaction was recorded (X-axis). See caption of Figure 5-13 for bar colour code description.

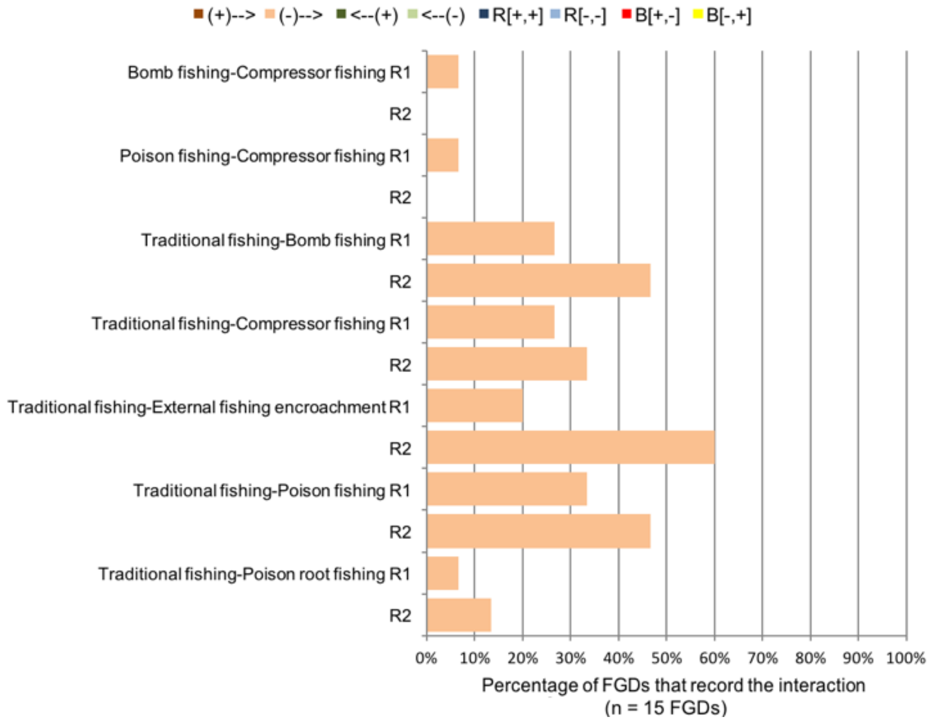

Figure 5-17. Stacked bar chart showing the composition of interactions between Activity variables (Y-Axis), for both the Round One and Round Two problem-mapping FGDs (*R1* & *R2*, Y-axis) based on the number of FGDs where the variable interaction is recorded (X-axis). See caption of Figure 5-13 for bar colour code description.

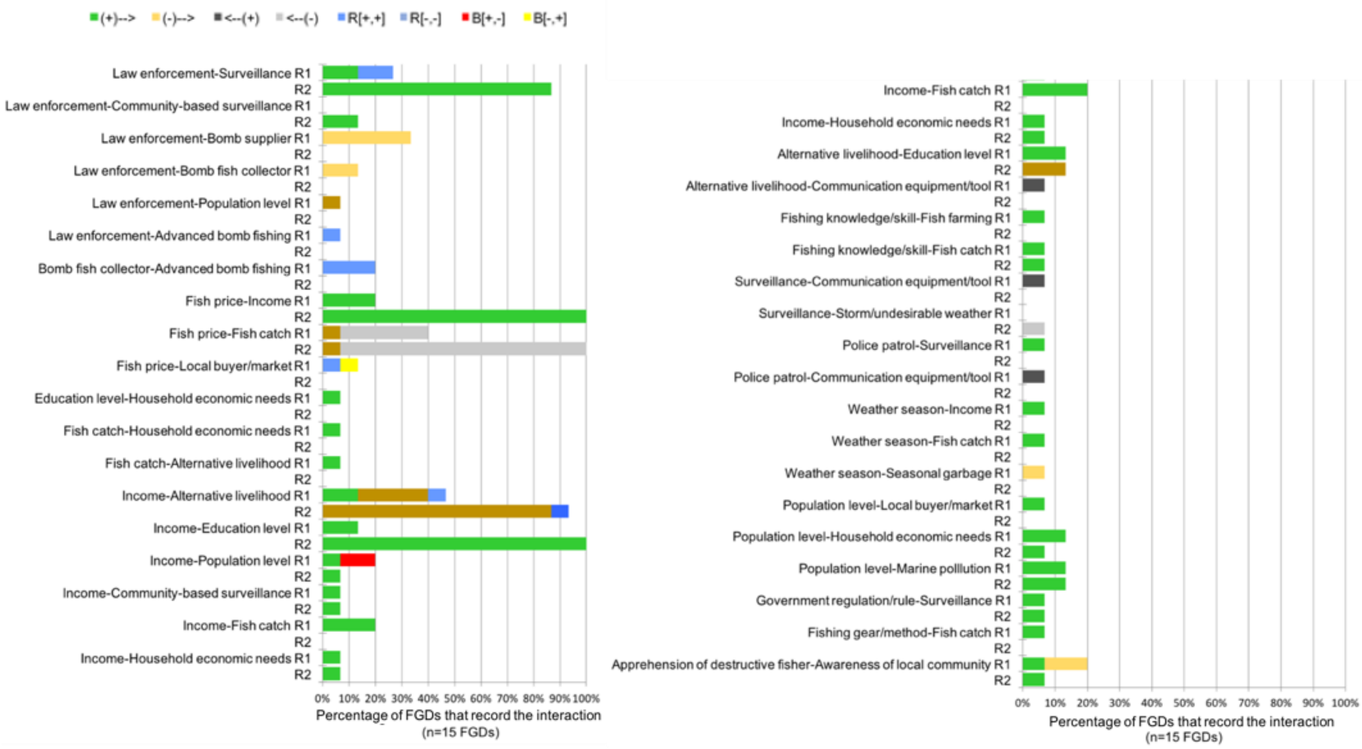

Figure 5-18. Stacked bar chart showing the composition of interactions between Pressure variables (Y-Axis), for both the Round One and Round Two problem-mapping FGDs (*R1* & *R2*, Y-axis) based on the number of FGDs where the variable interaction was recorded (X-axis). See caption of Figure 5-13 for bar colour code description.

5.1.2.5 Written notes describing comments by FGD participants

During the facilitation of problem-mapping FGDs, impromptu note-taking was performed if there was a commentary by participants, either spontaneous or the result of probing by the facilitator, that related to the mental information being sought in the facilitation script. However, since the roles of the Indonesian facilitators were already occupied for GMB tasks, note-taking was only done if it did not interfere with the role of the facilitators in the GMB activity and if the scripted problem-mapping steps progressed ahead of schedule. Therefore, not all of the FGDs allowed for note-taking. The summary of participants' comments during problem-mapping FGDs can be found in Tables 11 and 12 in Appendix 12.

5.2 Causal modelling and supplementary interview

5.2.1 Causal modelling

The causal loop modelling phase was composed of several analytical objectives (Cavana & Maani 2000; Sterman 2000):

(1) To develop CLDs (Section 5.2.1.1);
(2) To identify main variables (i.e., developing a boundary chart) (Section 5.2.1.1);
(3) To identify systems archetypes (Section 5.2.1.3);
(4) To identify potential key leverage points to propose strategies for problem interventions (Section 5.2.1.3); and
(5) To prepare reference modes/behaviour-over-time graphs (Section 5.2.1.4).

5.2.1.1 Causal loop diagram development (CLD) & analytical purpose

CLD (Sterman 2000) was used as a tool to visually asses feedback mechanisms that influenced the problem behaviour (e.g., in the BOTG: Section 5.2.1.4) by mapping the interaction of the system components (hence, the 'SES structures and interactions' in the conceptual framework: Figure 2-10), (hence, to explain the 'dynamic hypothesis') (Albin, Forrester & Breierova 2001). The main elements of a CLD are variables depicted as text, the direction of influence as arrows, link polarity as 'plus' or 'minus' signs, and feedback loops as 'R' or 'B' symbols (more in Figure 5-19). These graphical elements are translatable from the SESAMME map elements (Section 3.6.2.25.1.1.3) and were produced using the Vensim® PLE+ software. Following Sterman (2000), a feedback loop (Figure 5-19) was defined as a reinforcing or balancing loop by either tracing the assumption of change or counting the number of negative polarities. The tracing involves selecting any variable in the loop and assuming that the condition is increasing (or decreasing) and then following the loop around. A reinforcing loop is when the tracing ended in the same variable condition similar to the initial different for a balancing loop. As for counting, a reinforcing loop has an even number of or no negative links, and an odd number if it is a balancing loop.

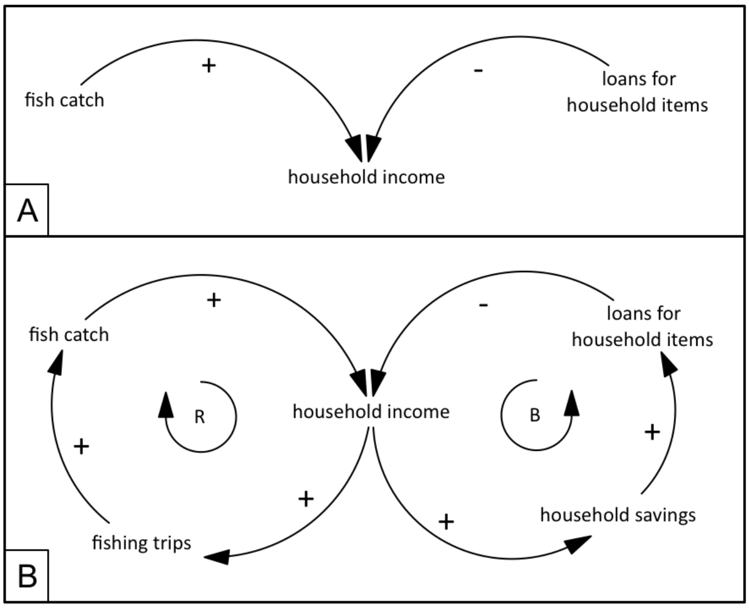

Figure 5-19. **Box A**: An example of a simple cause-effect interaction from three variables. The direction of influence goes from the variable at the arrow tail to another one at the head (depicted by the arrows). The change between two variables can move in the same direction (e.g., increased fish catch causes increased household income, depicted by the 'plus' link polarity sign), or in the opposite direction (e.g., more loans causing repayments that reduce household income, depicted by the 'minus' link polarity sign). **Box B:** An example of a series of interactions that produce closed cycles, or 'feedback loops'. A loop is 'positive feedback' or 'reinforcing' (marked with the letter R) when an increase in any variable produces the similar result (of influencing) more increases (or less in the case of a decrease) resulting in self-reinforcing growth or decline (Sterman 2000). The example shows that more income allows more fishing trips that in turn brings more fish caught for sales revenue that, therefore, promotes income growth. A 'negative feedback' or 'balancing' loop (marked with the letter B) is created when an increase of any variable brings the system closer to a goal (or further away, in the case of a decrease) in a self-correcting behaviour (Sterman 2000). The example shows an undesirable goal-seeking behaviour, whereby income is getting closer to zero as current income adds savings, which motivates families to take more loans that, however, incur repayments that reduce household income).

However, the CLD method has some limitations. For example, the link polarity describes the structure but not the behaviour of variables; the variables do not distinguish the stock and flow of information of materials, and consequently, more details are required as the loop is not specific (e.g., additional and specific variable names) (Sterman 2000, p. 67). These limitations were addressed by converting the CLD into a stock and flow diagram (SFD) later in the quantitative modelling phase (Section 3.6.4). Prior to the conversion, during the iterative steps in the problem mapping phase (Section 3.6.2), several essential versions of the CLD were generated, including:

- CLD 1: Draft-integrated CLD, developed by using information from the first round of GMB.

- CLD 2: Stakeholder-justified integrated CLD, developed by using primary information from Round Two of GMB by verifying bimodal elements identified in CLD 1 with stakeholder.
- CLD 3: Finalised CLD, developed as a synthesis between CLD 2, the results of interview survey for variable and relationship clarification (related method: Section 5.2.2), and the modellers' justification (by the team: Section 3.6.2, 3.6.3) based on peer-reviewed literature.

5.2.1.2 Model boundary determination and analytical purpose

A model boundary chart was developed to list (1) key variables that are included endogenously, exogenously, and/or excluded from the model; and (2) the associated literature on the concepts or principles (Conceptual framework: Section 2.4.1) that justify the identified conditions or processes in the system (Sterman 2000). The variables were derived from the variable element that was identified during the problem mapping process (Section 3.6.2) and the supplementary interview (Section 3.6.4) was incorporated in the final CLD (CLD 3). The chart provided a summary of the theories that were included or excluded in the model and at the same time serves as a reminder of the caveats in the results and the limitations of the model (Sterman 2000).

5.2.1.3 System archetype and leverage points identification, and analytical purpose

A system archetype is a generic (or, template) structure of a system commonly presented as a CLD (Nguyen & Bosch 2013) or as other graphical formats that use elements resembling CLD (Senge 2006). They provide the modeller with high-level information that describes commonly occurring patterns of system behaviour (Senge 2006). A systems archetype CLD generally consists of combinations of reinforcing and balancing feedbacks in two or more loops. It provides useful (but not exhaustive) insights about a particular topic, story, patterns of behaviour over time, system structures, mental models, or leverage points (Senge 2006).

The insights of previous data (CLD 2, BOTGs: previous sections) and the tested theories (e.g., path-dependent process: Section 2.2.4) directed the selection of one or more archetypes from the existing collections in the systems dynamics community (e.g., *The Fifth Discipline* by Senge (2006), *Archetype Family Tree* by ISEE systems ISEES (2006), and *Systems Archetype Basics* by Kim (1998)). The identified archetype(s) guided the development of CLD 3 (Section 5.2.1.1). To quantitatively assess the dynamics resulting from the feedback loops, the CLD 3 was then used as a seed systems map in the constructions stock-flow diagrams in the Dynamic Modelling phase (Section 3.6.4).

5.2.1.4 Reference modes delineation & analytical purpose

The term 'reference modes' refers to "… an abstract concept that represents a fabric of trends and shows how different variables change with respect to each other over time." (Sterman 2000, p. 90). Among the common method of presentation of reference modes is the behaviour-over-time graph (BOTG) (Saeed 1998). The BOTG is a graph comprising a horizontal axis that represents time and the changing variable in the vertical axis (e.g., Figure 5-20). BOTGs were developed to provide a qualitative reference point before the dynamic modelling process (Section 3.6.5) to gain confidence about the problem behaviours that needed to be alleviated throughout the modelling process (Saeed 1998). The BOTG also provides a conceptual depiction of the past as well as inferred future behaviour. The behaviour of variables presented in the BOTG was treated as patterns meaning in not describing the precise description of an event, but rather tendencies of behaviour or event snapshots (Saeed 1998). During the development process, the team relied on several sources of information to construct the BOTG, including:

- Stakeholder perceptions, which included data of the consensual perceived trends (the past, expected future, and desired future) associated to the variables (resources, activities, pressures) collected during GMB using the SESAMME app (Section 5.1.1.3).
- Secondary datasets, which included existing qualitative and/or quantitative data that could provide a concrete or abstract representation of the variable of reference (Khan, McLucas & Linard 2004).

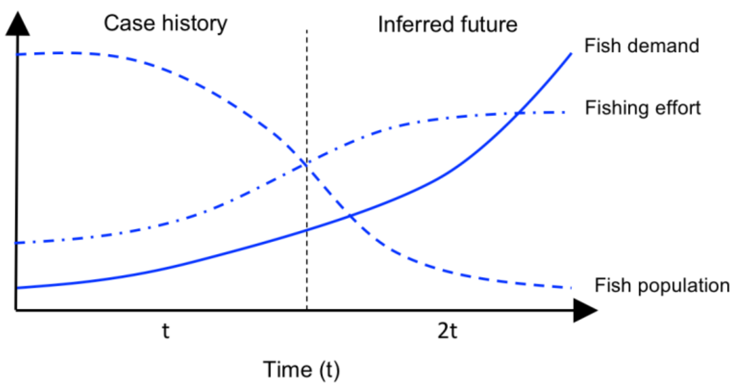

Figure 5-20. An example of a behaviour-over-time-graph.

5.2.2 Supplementary interview for causal model justification

5.2.2.1 Interview design and question topics

A semi-structured interview survey (De Vaus 2002; Leavy 2014, pg. 277) was conducted after the development of CLD 2 (see Section 5.2.1.1). 'Structured' in this case refers to the respondent being asked the same questions in the same order (Krueger & Casey 2009). This condition applied to the ‘semi-structured’ interview, however, allowing new ideas to be suggested by the interviewer as a result of the interviewee’s response through the use of pre-defined probing questions or cues.

During the interview, a list of open-ended questions was used to gather qualitative information such as conditions related to attitudes, or orientation or actions associated with social and economic decisions made by individuals in the past or future. The information was used mainly to clarify the hypothetical system component (variables) and/or influences (interactions between variables) that were introduced during the development of CLD 2, and which mainly related to the topic of *alternative (non-fishing) livelihood activity*, *loan taking* experience, and strategy to cope with a *household deficit* (the associated variables are in italics).

The three topics being enquired about in the interview were primarily chosen based on several selected participant’s comments that were noted during the facilitation but not recorded in the SESAMME maps during the problem-mapping FGD. The comments were selected in accordance with their relevance to the topic problem (or the background problems related to the small-scale fishery in Indonesia (see Section 1.2, Chapter 2). At the time of the CLD 2 development (Section 5.3.2) a number of questions were raised, including:

1. How do non-fishing livelihood activities take place and influence fishers’ livelihoods?
2. How do the fishers/fishing households come to take out loans and how do they cope with debt-related problems?
3. How do fishers or fishing households cope with the household deficit?

Since there was no information specific to the Selayar region that could address these questions, several exploratory question topics were developed (in Table 5-4) that were structured in a question route (0). The tabulated response data from the interview (Appendix 16) was triangulated to confirm or introduce new variables and interactions which updated CLD 2 and led the team to construct CLD 2.5 (for related results see Section 5.4, Figure 5-29).

Table 5-4. Question topics developed to address each key question. Each topic is associated with a question code that relates to the supplementary interview question route form (Appendix 15).

Key questions	Question topic	Question code
How do non-fishing livelihood activities (if any) take place and influence fishers’ livelihood?	Current non-fishing job	Q11
	Desired non-fishing job	Q12
	Past experience in the non-fishing job	Q13
	Reason for taking an additional job	Q14
	Household needs unfulfilled when there is no additional job	Q15

Key questions	Question topic	Question code
	Household needs still fulfilled when there is no additional job	Q16
	Willingness to spend more time in a job other than fishing	Q17
	Willingness to stop fishing and working only in the additional / non-fishing job	Q18
	Reason for adjusting (reducing or adding) working time in fishing and additional job	Q19
	Reason for not engaging/not wanting to engage in the additional job	Q20
	Involvement of household members in the additional job	Q21
	The factors that enable the respondent to do the additional job	Q22
	The factors that prevent the respondent from doing the additional job	Q23
	Factors perceived to be the most essential/critical to enable the respondent to run the job	Q24
	Reason for choosing the job	Q25
How do the fishers/fishing households come to take out loans and how do they cope with debt-related problems?	Past experience in loan taking / or asset borrowing	Q26
	Future plan on taking a loan	Q27
	Loan frequency	Q28
	Reason for taking a loan	Q29
	Reason for not taking a loan	Q30
	Creditors/Lenders	Q31
	The credit arrangement(s), and the perceived fairness of the credit arrangement	Q32
	Source of funding, income allocation for loan repayment	Q33
	Forms of collateral, and the penalty for outstanding debt	Q34
	Financial management in case of overdue or owing loan repayment	Q35
	Coping strategy to address debt or overdue repayment owing	Q36
How do fishers or fishing households cope with the household deficit?	Past experience in managing household deficit	Q37
	Strategy to monitor the household financial condition	Q38
	Ability to foresee a household deficit	Q39
	Situations signalling that household deficit or financial problem is drawing nearer	Q40
	Strategy to cope with the ongoing household deficit or financial problem	Q41
	Strategy to mitigate upcoming household deficit or financial problem	Q42
Respondent’s profile	Interview date	Q1
	Village	Q2
	Sub-village	Q3

Key questions	Question topic	Question code
	Age	Q4
	Year married	Q5
	Household size	Q6
	Number of children	Q7
	Type of fishing boat	Q8
	Type of fishing gear	Q9
	Dependence on fishing	Q10

5.2.2.2 Native speaking interviewer

The interview was conducted within a limited time frame between the 19th and 25th of September 2016, owing to the availability of the local assistant and the author's research time constraints. I appointed and trained Diansa Tosilajara (or, Ardhi) as the native interviewer and consultant for the interview planning. At that time, Ardhi was partnering with Pak Andi (our local collaborator, Section 3.5) to assist with the team's fieldwork engagement with the Selayar community members. Ardhi was also familiar with the scope of the CCRES research project.

5.2.2.3 Interview delivery

A question route form was prepared to guide the native interviewer in delivering the main questions and for providing structure for probing (in 0). The form was also designed to help organise note taking directly in the form during the interview in Bahasa since the question delivery and conversations were in Selayarese language. Ardhi suggested that using Selayarese language, would make community members more open due to the more 'informal' interaction and better delivery of questions that might be considered sensitive, and when clarifying questions or answers. The interviews were voice-recorded whenever the respondent's consent was received.

5.2.2.4 Interview location, participant selection and criteria

A supplementary interview was conducted in each of the seven FGD villages previously visited during the problem-mapping activity, namely: Barat Lambongan, Bungaiya, Mekar Indah, Barugaiya, Parak, Benteng,and Bontoborusu. Each interview visit was made only after prior contact with the village staff to determine when fishers would likely be at home. In each village, the respondent selection was made by randomly selecting a person from each of the sub-villages (*dukuh*) of each of the seven FGD villages previously visited during the problem-mapping activity (For interview dates and sub-village namesm see Appendix 12). Interviews were initiated if the selected candidate was willing to be interviewed and have their audio responses recorded; otherwise, another random selection was made. Fishers who declined the interview request were asked to suggest a substitute candidate in their sub-village. The respondent criteria were that a particular sub-village member had been, and was currently, involved in the fishing-related activity, and used their income to a household of any size.

5.3 Results from the causal modelling

5.3.1 CLD 1 based on the results of the Round One problem mapping

After the Round One problem-mapping FGDs, a single large and detailed CLD (or 'CLD 1', about CLD: Section 5.2.1.1), was able to be constructed using the information from the SESAMME maps such as the Resource, Activity, and Pressure variables; the interactions, and the identified feedback loops. The information was based on map elements that has the highest number of FGDs that record it. The detailed version of CLD 1 can be found in Diagrams 1A and 1B in 0. The team treated this version as the 'common CLD' as it was based on the highest-occurring rich picture elements from all FGDs and was used to identify and mark bimodal elements (by comparing it with the individual SESAMME map from each of the Round One FGDs).

Since CLD 1 would need to be explained in Round Two (i.e., as a story); a simplified version of CLD 1 was developed (Diagram 2, 0). To further reduce the complexity when explaining the problem structure, the simplified CLD 1 was then separated into several segments of CLD that isolate or selectively highlight the variables and interaction (i.e., CLDs in Figure 5-21 to Figure 5-27). These segments were used during the Round Two FGDs to inform participants of the 'lessons learned' about the system before asking them to compare their Round One SESAMME maps and the CLD 1 (i.e., review the bimodal elements, at the same the review mode is displayed in the SESAMME app [Section 5.1.1.3]).

From the interaction between resources, a reinforcing feedback loop between fish and coral was identified (loop R1, Figure 5-21). The acknowledgement is in line with the existing scientific findings such as the positive influence of coral reef structure complexity on maintaining fish populations (Rogers, Blanchard & Mumby 2014), and the population of particular fish species keeping coral reefs from becoming overgrown by certain macroalgae species (Bellwood & Choat 1990). The fish condition was also positively influenced by the seagrass condition, which is consistent with the global findings, such as the work of (Cullen-Unsworth et al. 2014).

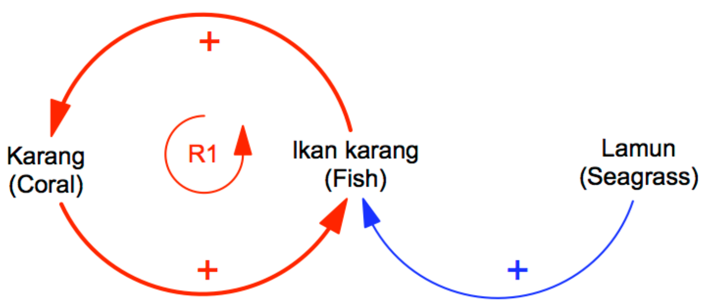

Figure 5-21. Part of CLD 1 showing interactions between Resource variables.

However, from the interaction between activities, a variety of fishing groups originating in both Selayar and other areas are diminishing the local fish population (loop B1 to B4, Figure 5-22). At the same time, the activities of destructive fishing groups (i.e., bomb/blast fishing, poison /cyanide fishing) are eroding the fish habitats, which further reduces the chance of the fish resources recovering during an intensive fish harvest.

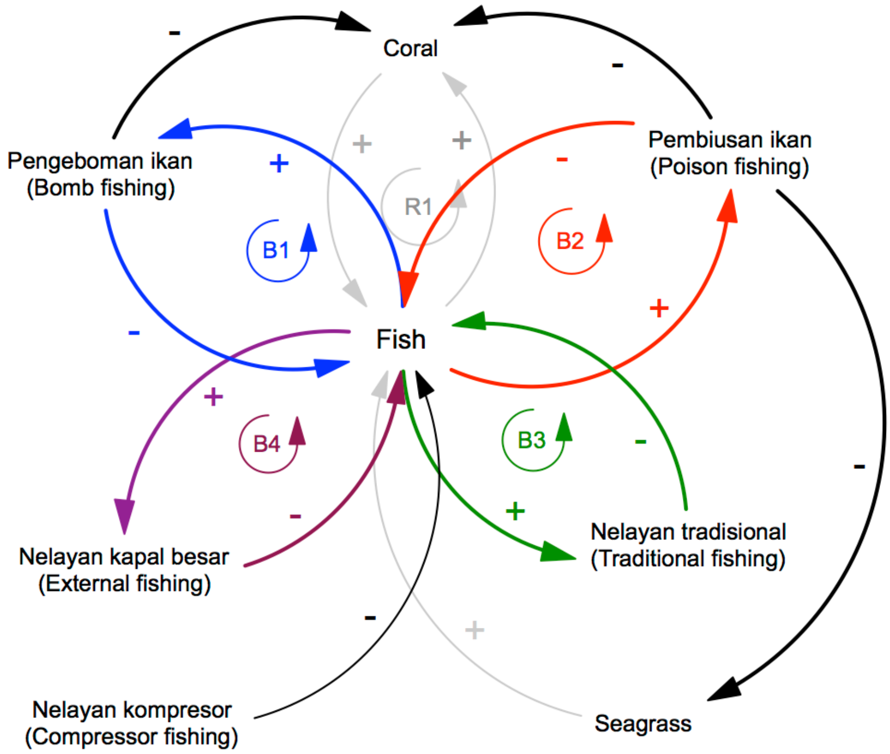

Figure 5-22. Part of CLD 1 showing interactions between Resource and Activity variables that form several balancing feedback loops (B1 to B4).

In relation to the destructive fishing, as shown in loop R2 to R5 of Figure 5-23, the blast and cyanide fishers attached to and supported by 'patrons' who may be both as the fish buyer and the supplier of destructive fishing gears. The ties can also be relational, creating a sense of "moral duty" between the patron and the client, thus enhancing the continuation of the activity (Adhuri et al. 2016; Miñarro et al. 2016). Referring to the loop B5 to B7 in Figure 5-24, some (but not all) village members are aware of the potential impact of destructive fishing and external fishing on their village's fishing ground, increasing the need for independent surveillance activity to deter these fishing activities.

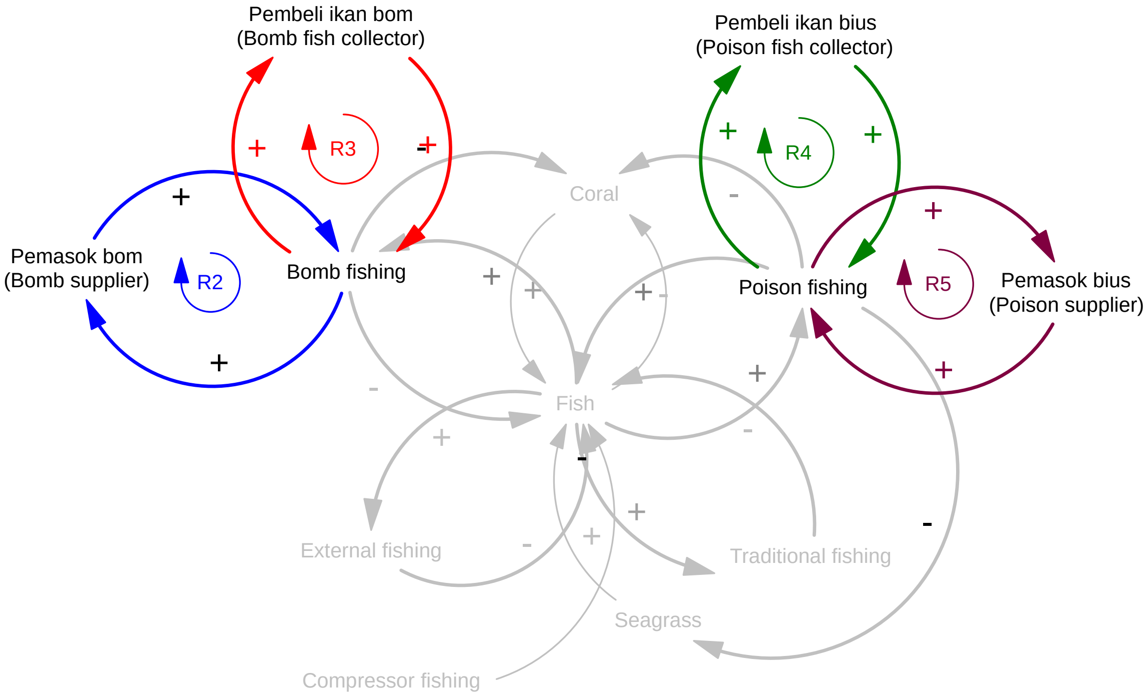

Figure 5-23. Part of CLD 1, expanded from Figure 5-22, showing interactions between Pressure and Activity variables that form several reinforcing feedback loops (R1 to R5).

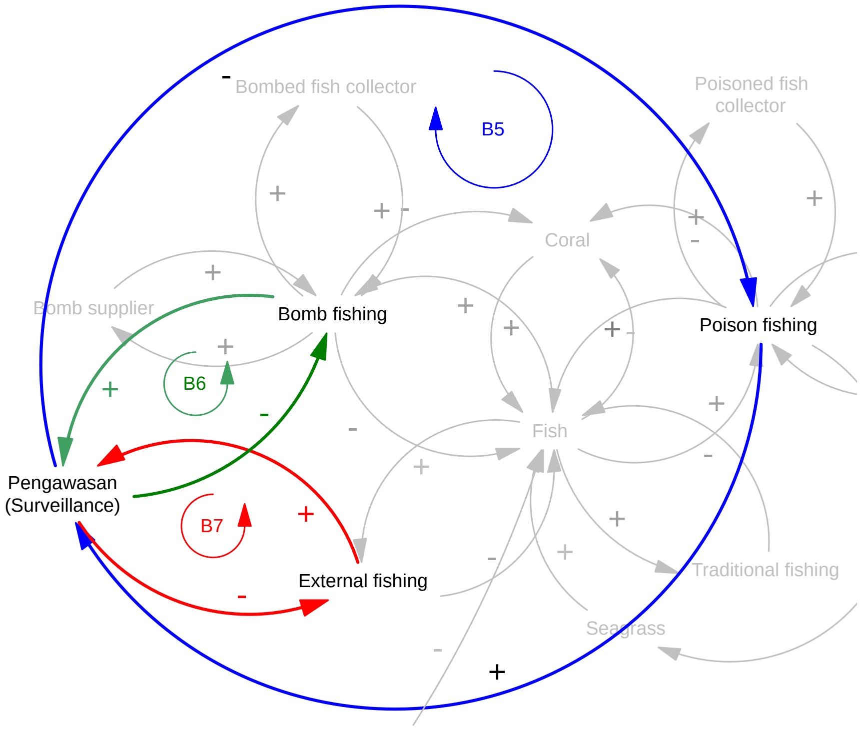

Figure 5-24. Part of CLD 1, expanded from Figure 5-23, showing interactions between Pressure and Activity variables that form several balancing feedback loops (B5 to B7).

From the interactions between activities and pressures, fish was not the only motivating factor for fishing. Factors beyond the control of individual fishers or households (i.e., exogenous) also played a part, including fish price, the predictability of weather conditions, and the local population (i.e., household size, which reflects financial burden) (blue arrow lines, Figure 5-25). At the same time, surveillance, law enforcement, alternative livelihood, education, and weather hazards are the exogenous factors that can demotivate local fishing activity (blue arrow lines, Figure 5-25). Surveillance was deemed to be uncontrollable since the effectiveness of surveillance largely depends on a collective effort (i.e., it is not a task that a fisher or household can handle alone). The effectiveness was also perceived to be linked with a functioning law enforcement seeing that the apprehension of destructive fisher by the community should also be followed with a deterrent legal punishment. The additional income stream from alternative livelihoods was deemed to provide a crucial financial buffer for fishers seeking to reduce their fishing time (i.e., due to the risk involved). Similarly, it was deemed that household capacity to finance tertiary education could promote emigration for studying or working outside the island, which would therefore reduce the number of current or future fishers, particularly in the younger age groups.

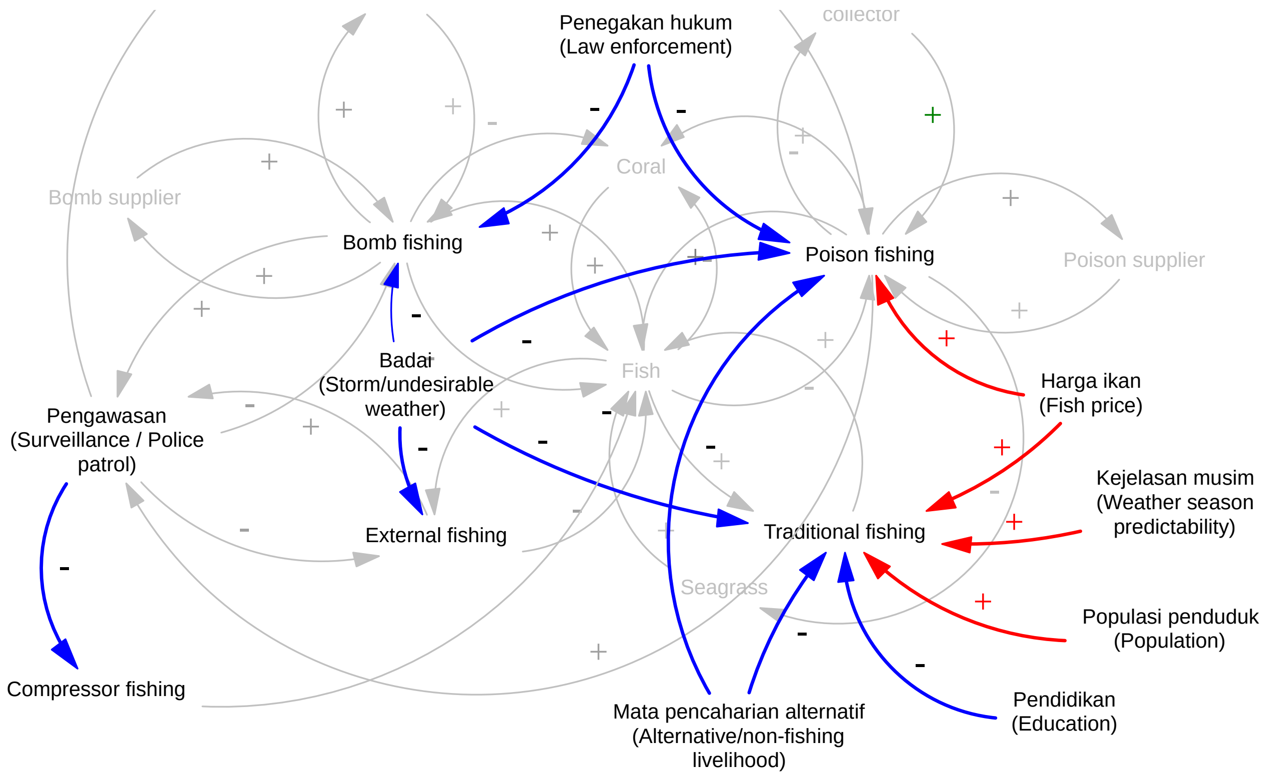

Figure 5-25. Part of CLD 1, expanded from Figure 5-24, showing exogenously influencing variables interacting with Activity variables.

From the interaction between activities depicted in (Figure 5-26), the presence of non-destructive traditional fishers can deter destructive fishers. During the FGDs in the villages that openly opposed to destructive fishing (e.g., Barugaiya), the resident fishers stated that they have and would continue to proactively monitor their fishing ground for destructive activities and, if possible, apprehend the destructive fishers.

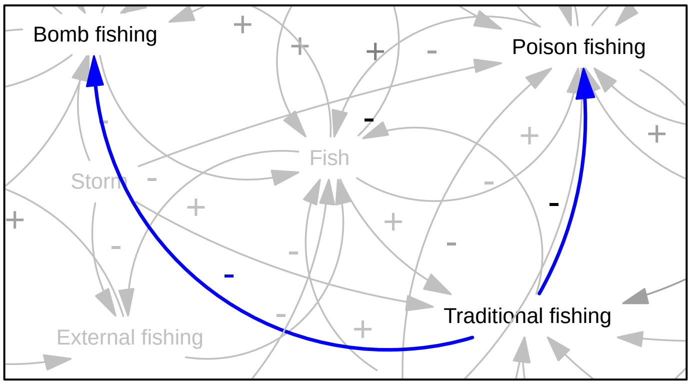

Figure 5-26. A selective highlight of CLD 1 showing the interaction between Activity variables.

The interactions between pressures indicate that (Figure 5-27) the level of education (i.e., tertiary) in the household depends on the amount of income derived from fishing and, if there is any, from supplementary occupations (i.e., alternative livelihood). At the same time, fishing income and fish price are negatively influenced by fish catch. Since local fish sales are restricted due to the stagnant or declining number of local fish buyers, local oversupply can occur and trigger price deflation, thereby reducing the income from fishing despite the increased fishing effort. Avoiding or detaching from this underperforming livelihood may not be easy for some households since education improvement is financially difficult to achieve. Supplementary occupation/s may be absent or there could be a lack of productivity while the fish resources are being exhausted.

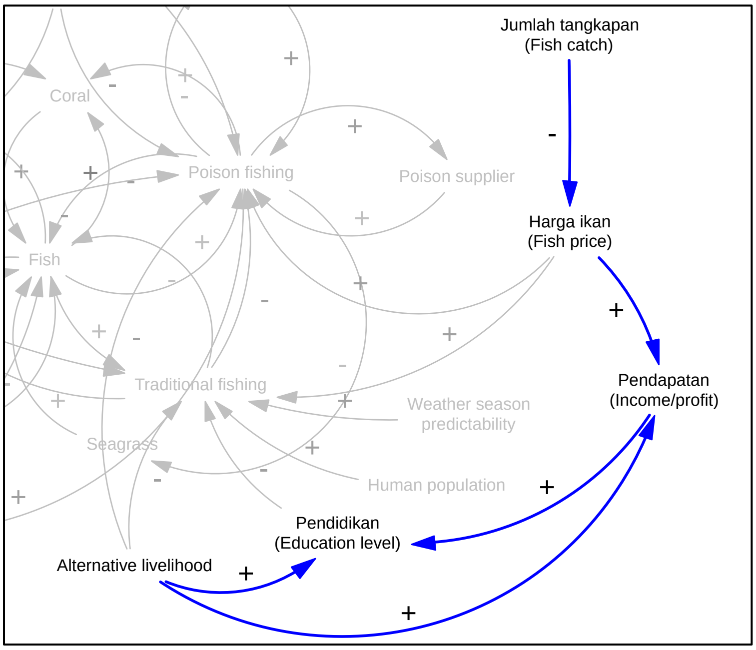

Figure 5-27. Part of CLD1, expanded from Figure 5-25, showing the interaction between the Pressure variables.

5.3.2 CLD 2 based on the results of the Round Two problem mapping

In the Round Two of the problem mapping FGDs, participants reviewed their rich pictures (SESAMME maps), compared these with the common CLD (CLD 1), and decided whether to keep or revise any bimodal elements. This was the way they produced the finalised consensus rich picture. The team repeated the post-FGD process performed in Round One and developed a single large and detailed version of CLD 2 from the finalised rich pictures from the Round Two FGDs. Similarly, CLD 2 was constructed using the Resource, Activity, and Pressure variables; the interactions, and the identified feedback loops based on the SESAMME map elements that has the highest number of FGDs that record it (Appendix 14).

Since the amount of information captured in the Round Two rich pictures had increased, a less-detailed version of CLD 2 was then developed (Figure 5-28). CLD 2(Figure 5-28) includes variables and interactions based on the extracts of the Round Two rich pictures (black text and arrow lines) and hypothetical conditions learning from the literature review (blue text and arrow lines). The variables presented in CLD 2 refer to conditions/processes inferred from one or several rich picture variables (uppercase text in parentheses).

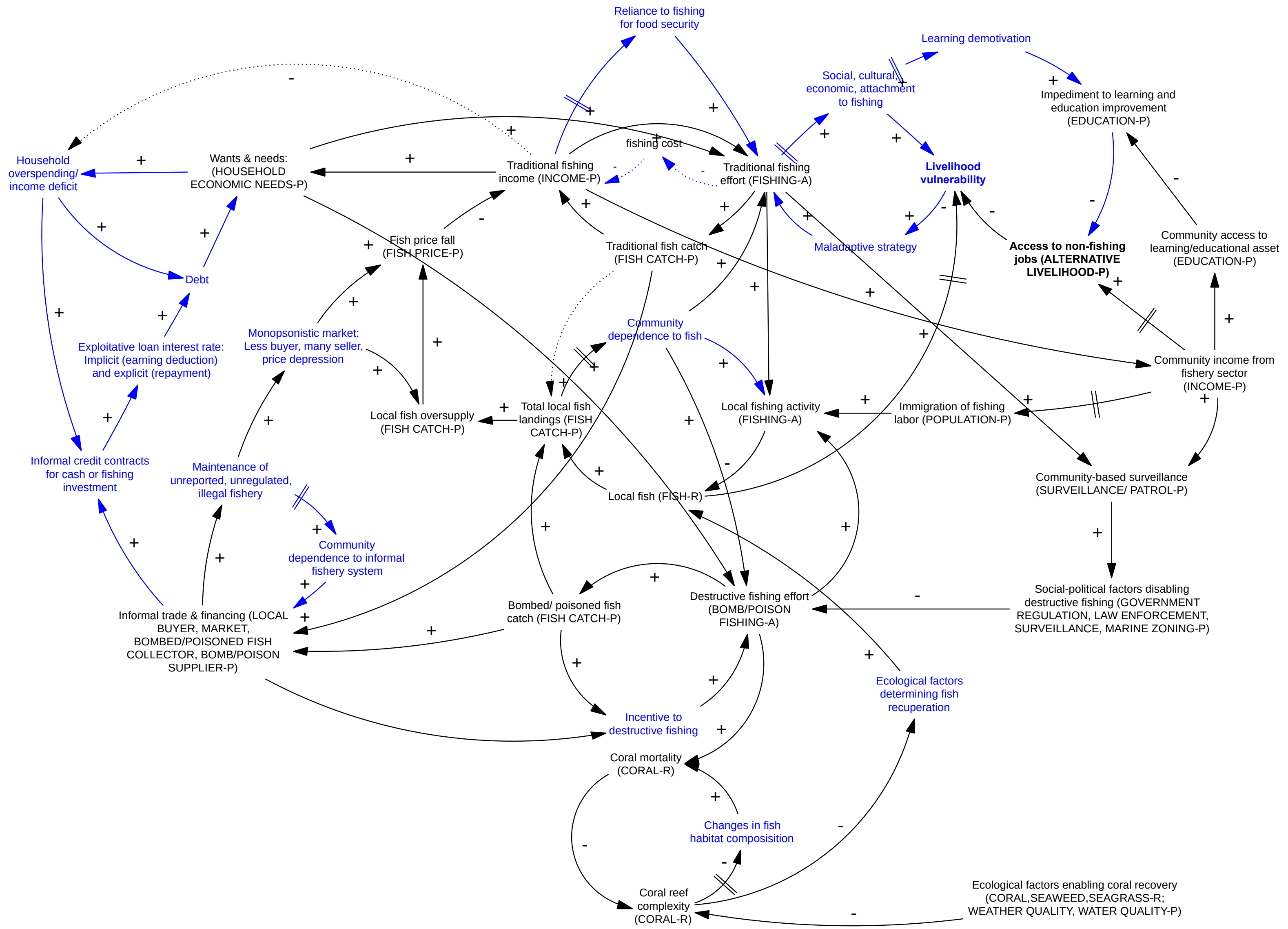

Figure 5-28. The simplified version of CLD 2 (presented for landscape orientation viewing). Variables names were redefined from one or several recorded variables in the rich pictures (uppercase text in parentheses) under a particular variable group (R=Resource, A=Activity, P=Pressure).

5.4 Results from the supplementary interview

5.4.1 Interview respondent profile

A total of eighteen respondents were able to complete the interview in the fieldwork period from the 19^{th} to the 25^{th} of September 2016. The table of information extracted from the interviewer's questioning guide (Appendix 16) indicates that the interview covered all seven of the problem-mapping villages with one respondent randomly selected from each *dukuh* or sub-village (Q1-3). All respondents were male fishers ranging in age from 37 to 63 (Q1-3, Appendix 16), 15 of whom reside in a household comprising 1 to 7 members (including 1 - 5 children). All respondents were reliant on fishing as their main income-generating activity and used a traditional fishing method (artisanal fishing gear: hand line, lift net, purse seine net) (Q5-10, Appendix 16).

5.4.2 Interview survey result

The native interviewer related the responses to each of the main interview questions and this information was extracted and tabulated in Appendix 16. The information in the table was thematically grouped according to the question route form topics of (1) Alternative livelihood (Q11-Q25, Appendix 16), (2) Loan taking (Q26-Q36, Appendix 16), and Household deficit (Q37-Q42, Appendix 16). The retell was partly sourced from the interviewer's notes on the question responses written directly in the question route form, and partly from the voice record of an interview where clarification was required for responses that were not specific. Since the interview conversations were predominantly conducted in Selayaranese, I needed to convert each response retelling into informal Bahasa Indonesian first (see responses inside quotation marks, Appendix 16) with the help of the interviewer.

In general, key findings from the interview provided information that clarified hypothetical variables and interactions introduced in CLD 2 (blue text and arrows in Figure 5-28) and added new variables and interactions. The modelling team conducted the analysis by triangulating the information from the interview response (Appendix 16) to establish a consensus for a worldview (following Checkland and Poulter (2010)) of a case, which is presented using variables and interactions that were visually recorded as CLD 2.5 (Figure 5-29).

Based on extracted interview responses (Appendix 16) and referring to the elements of CLD 2.5 (Figure 5-29), the identified experience of fishers engaging in non-fishing livelihood activity confirmed one of the hypothesised variables, namely the *alternative livelihood.* From answers related to the motivation and factors that have brought fishers to perform non-fishing jobs, it could be seen that the diversification of the household income generation strategy depends on several internal factors such as *the attractability non-fishing job over fishing* (e.g., profitability), *spare* *working time,* and *labour support from another household/family member.* Several exogenous factors were also identified, such as *experience in the non-fishing job, the availability of labour support* outside of the household, *access to raw material* such as *land for farming* and were found to be influential in enabling fisher/household to engage in a non-fishing job. In CLD 2.5, these variables are indicated by green text and black arrow lines for the interactions. In addition to the identified prerequisites for enabling a fisher/household to engage in an additional non-fishing job, there are also exogenous influences that increase the *risk in the fishing job* such as *weather hazards* and health limitations such as *ageing* fishers and which diminish the attraction of fishing (interactions marked by red arrow lines),

Furthermore, the question responses related to loan-taking experience and household deficit suggest that the majority of Selayar fishers might have previously taken (or be currently taking) regular *cash loans*. *Loan taking* was found to be motivated by the need to offset unfulfilled *household needs,* which can either be due to insufficient *household income* or *costs of living (primary and auxiliary)* that are too high. In this case, the *costs of living* could also include *fishing costs* and *non-fishing job costs.* At the same time, *loan taking* introduces additional *costs of living* from *loan interest* and *penalties.* The decision to take a loan can be externally motivated due to the availability of cash lenders and collateral assets, and internally prevented due to *risk-averse behaviour* of fishers/households. In CLD 2.5, the interactions of these variables are indicated by brown arrow lines.

Lastly, referring to the blue arrow lines in CLD 2.5, I identified new interactions associated to the income regulation of fishers/households. These interactions were specifically related to the reason for loan taking and the capacity to foresee and cope with deficit. The responses indicated that *the fulfilment of needs* depends on the *household income target* that acts as a fulfilment threshold and the *total household income* that allow the realisation of the *needs*. The level of *needs fulfilment* sets the *income goal* and, therefore, the allocated *effort for non-fishing job/fishing job* in the future. The *fulfilment of needs* also means that the *costs of living* are inherently offset.

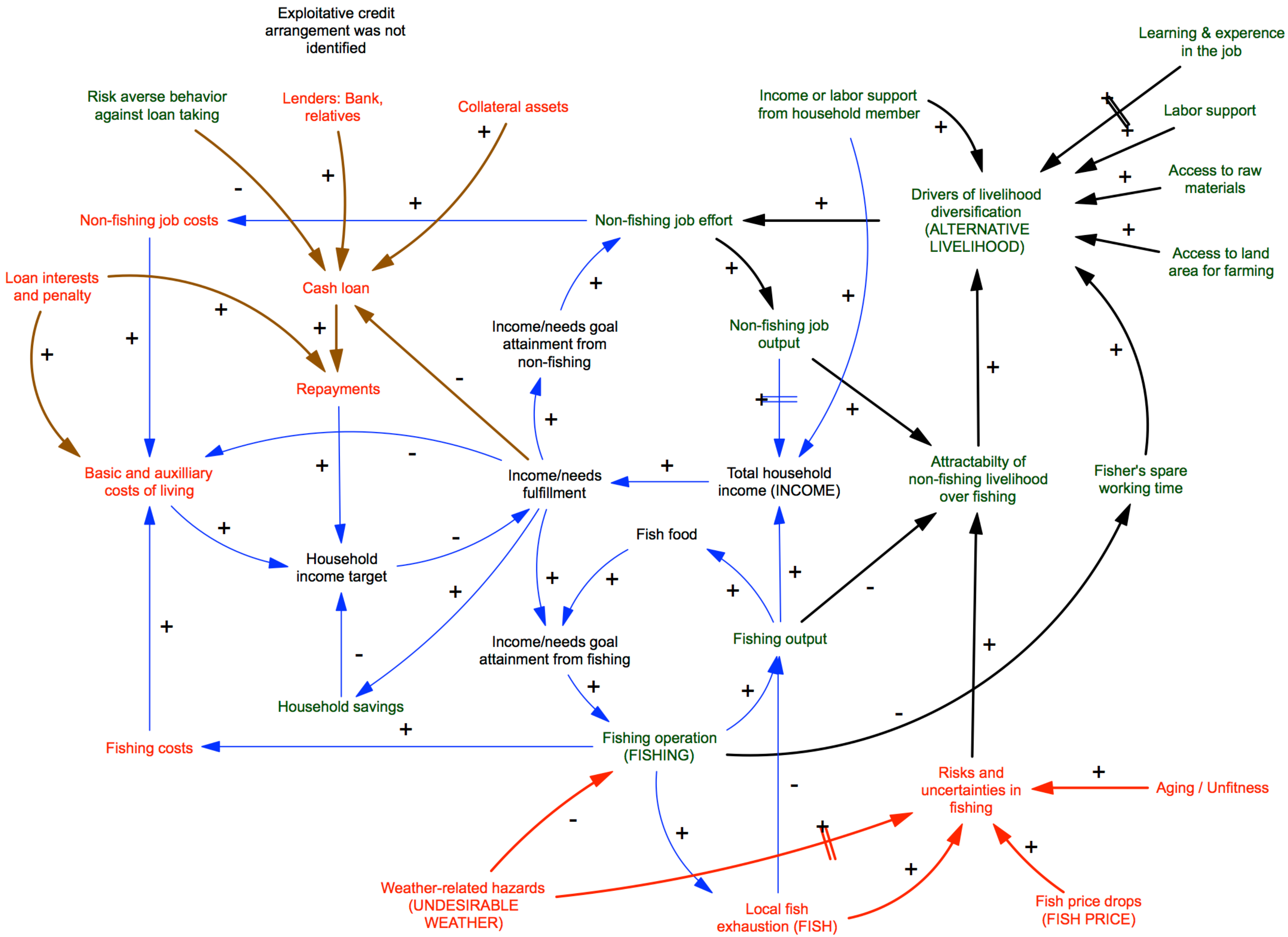

Figure 5-29. CLD 2.5 is derived from the key findings from the supplementary interview results.

Figure 5-29 depicts the variables and interactions from the interview answers that were linked directly and indirectly to the variables pre-identified in CLD 2, such as ‘Fishing’, ‘Fish’, ‘Fish price’, ‘Undesirable weather’, ‘Income’, and ‘Alternative Livelihood’ (variable names in uppercase text in parentheses). Furthermore, these variables were perceived to be associated with additional variables that were considered to have an undesirable as well as a desirable influence (see variables in red text and green text, respectively) to the financial status of the fishing-dependent household (see variables in black). These variables were found to be influential largely at the household-level through interactions that provided substantial explanations for (1) respondents’ experience of debt-related problem (see brown arrows); (2) respondents’ willingness, need for, and/or perceived requirement to adopt, engage, or to improve a particular non-fishing job (see black arrows); (3) their perceived increasing risks in fishing activity (see red arrows); and (3) their household financial strategy that had been or were accommodating multiple source of income (see blue arrows).

5.5 Results from the causal modelling: CLD 3

In consultation with team members with a background in and/or experience in dynamic modelling (CS, RR, NS, SK, LA), I developed CLD 3 (Figure 5-30, Figure 5-31) based on the synthesis of the structure of CLD 2 and CLD 2.5. In general, CLD 3 provides additional information on the variables and interactions occurring at the household level (blue text and arrow lines, Figure 5-30, Figure 5-31) in addition to the community-level processes from CLD 2 (black text and arrow lines). Referring to the same figures, additional undesirable and desirable influences of externally influencing variables were also identified (red and green text, respectively) both in household and community level interactions. In the development and consultation of CLD 3, merging of several variables and corrections to variables names, interactions, and/or polarity were made mainly for clarification and to conform to general knowledge or general scientific facts proven conditions based on peer-reviewed literature (elaborated as part of the discussion in Section 5.6).

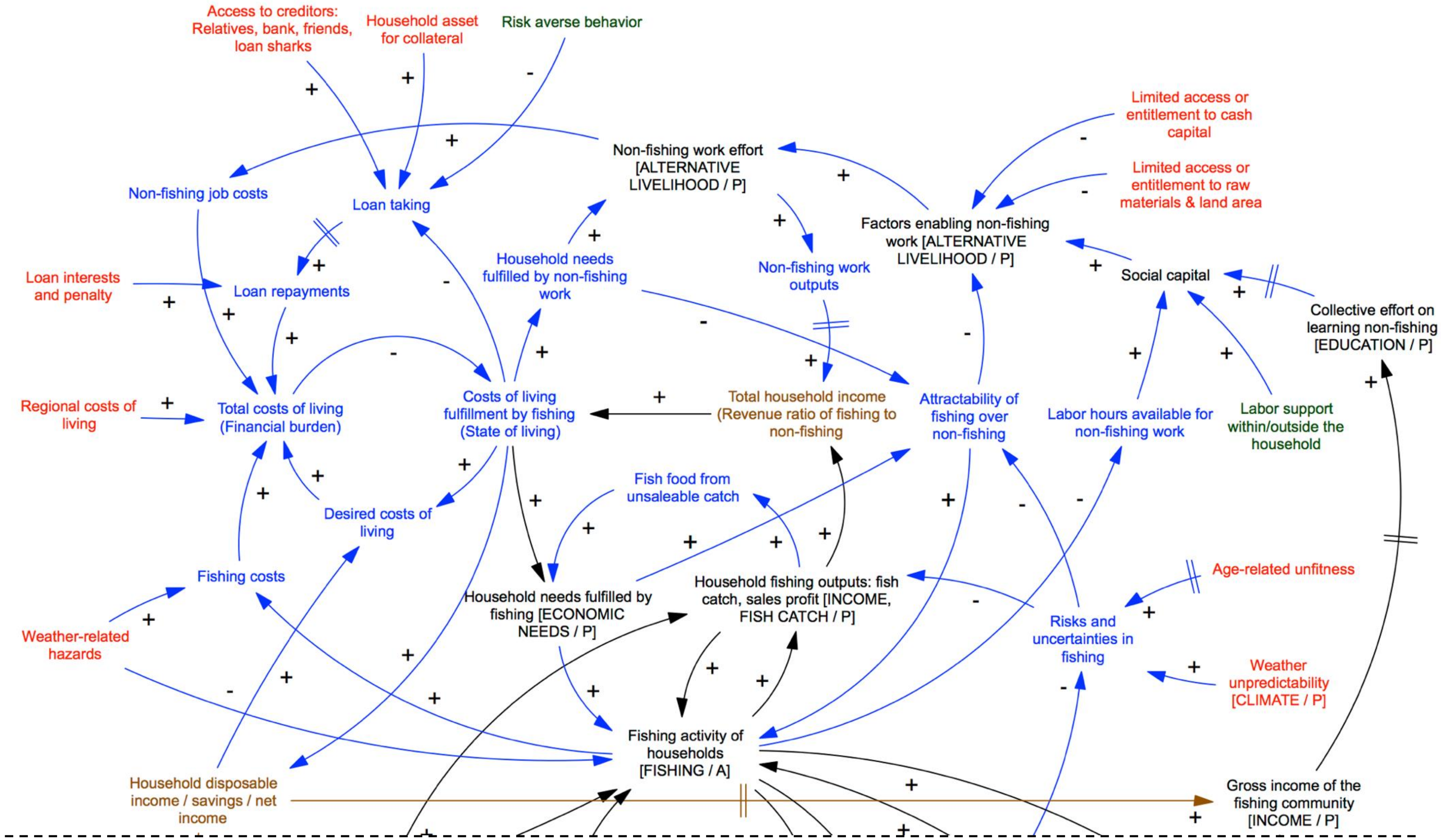

Figure 5-30. Top segment of the CLD 3 derived from variables and interactions derived from the problem mapping (variable names in square brackets and black arrows, respectively) and the supplementary interview (variable names without square brackets, blue text) including exogenously influencing variables (red and green text, respectively); and few intermediating variables (brown texts and arrows).

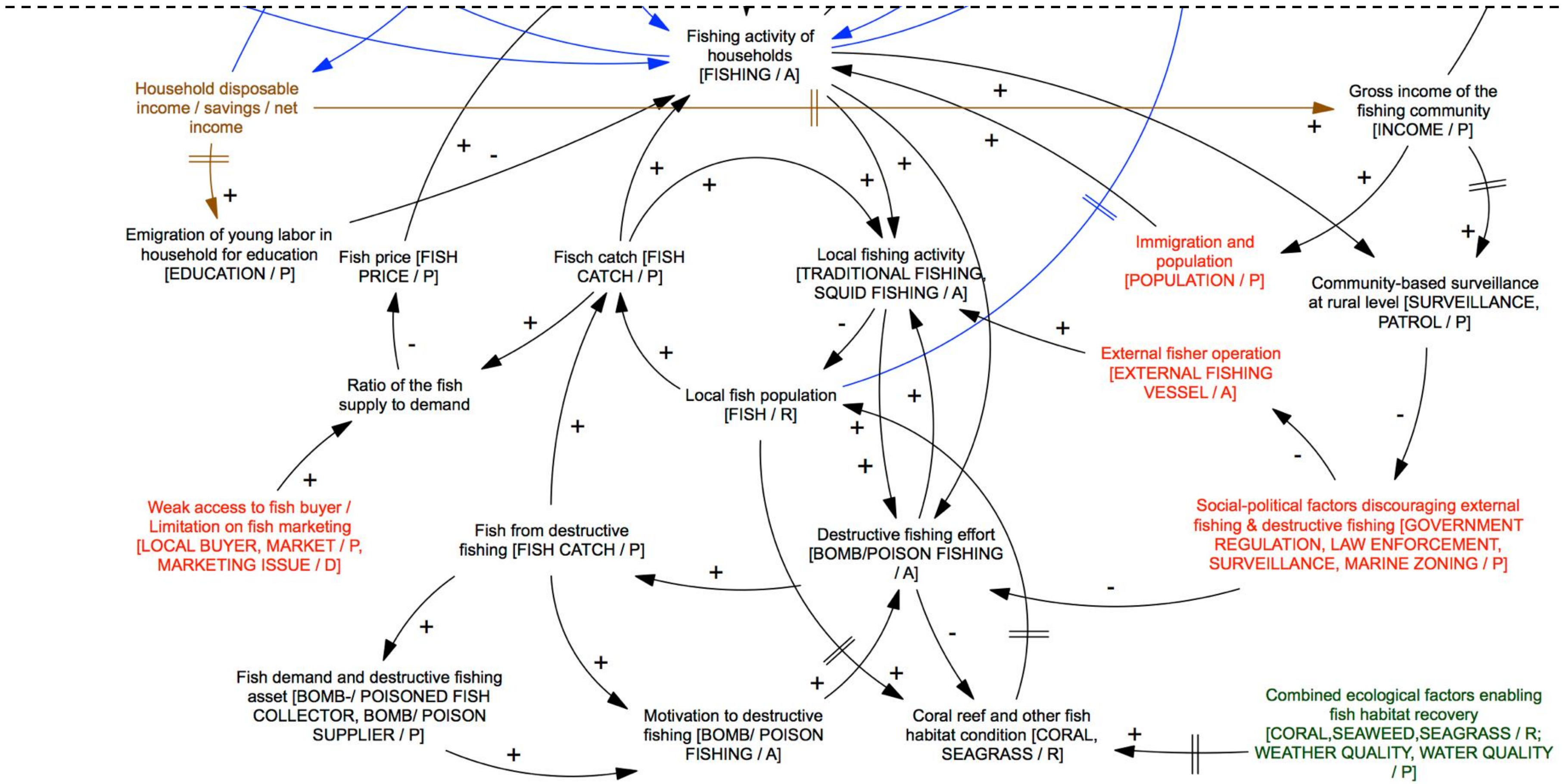

Figure 5-31. The bottom segment of the CLD 3 in Figure 5-30.

5.6 Discussions

5.6.1 The socio-ecological boundary of the system

By triangulating findings from the final causal model (Figure 5-30, Figure 5-31) and information from the supplementary interviews, the system components and/or processes that characterise a social-ecological system (SES) were identified for the study site and are in agreement to the findings from other coastal and marine SES studies (Model boundary chart: Table 5-5). Furthermore, multiple variables were apparently captured in the causal model which involves a diverse set of both human- and non-human-related variables. This analysis justifies the 'declining reef fisheries' problem-of-interest in Selayar as a 'systems problem'. In relation to the sustainable livelihood framework (Section 2.2.1), the problem topic was endogenously influenced by state variables (about: Section 2.2.4, variables: Figure 5-32) that were found to be linked to either human (i.e., fisher), social (i.e., fishery groups), financial (i.e., fish price), physical (i.e., access to fishing or farming area), or ecological assets (i.e., marine and terrestrial livelihood resources), as well as exogenously influencing variables (e.g., weather conditions, access to market/fish buyer, regional costs of living, fish ecosystem condition, non-Selayar fisher); which are present in a complex interaction (directions of influences, see arrows in Figure 5-30, Figure 5-31).

Table 5-5 shows the social, economic, ecological, and governance aspects of the Selayar small-scale fishery system that were found in the literature examining the phenomena through an SES lens. The social aspects include social conditions or processes, such as the system actors' perception of the ecological resources and services, the influence of various kinds of human activities, the socio-economic priorities, livelihood goals, norms, and attitudes that influence the conduct of livelihood activities, the actors' awareness of or compliance to existing resource-use-related regulations, collaborative mechanisms between actors in the social subsystem, and the flow of information between the actors that influences social learning about the associated social subsystems. Furthermore, the economic aspects include economic conditions or processes, such as the influence of financial return (i.e., income), the value and price of the natural resource-based livelihood commodities, forms of incentive that are internally and externally introduced and motivate the livelihood activities, the role of the market and its relationship with supply, demand, and value of the commodity, and the influence of innovation and technology (e.g., to improve livelihood operation and collaborative actions). The ecological aspects include the condition of the higher and lower trophic fish species groups that are essential fishery-based livelihood commodities, the biogeochemical environment (i.e., the circulation of essential elements of living matter) that influences the condition of the fishery resource, the physical environment that affects the conduct of livelihood activity in particular, and the flow of information about the state of the ecological resources through the system actors' collective informal learning (e.g., traditional, non-scientific knowledge). Conditions related to the governance of livelihood, as a subset of the social aspects, were also identified. It includes the varying awareness and support of livelihood actors to the policies, rules, or regulations – of both those that are internally (i.e., by the community) or externally (i.e., by the government) imposed, which can be compatible or conflict with their livelihood values and prompt certain community response attitudes or behaviours. The above traits of the Selayar small-scale fishery, therefore, suggest that the conceptual model of the *declining reef fisheries* problem (i.e., CLD 3) is intrinsically a depiction of an SES.

Table 5-5. Model boundary chart summarising the association of the information obtained from Activities 2, 3, and 4 (e.g., selected variables in CLD3 [in italics], states and trends in the SESAMME maps, noted comments during FGD, and supplementary interview responses) to the findings of other studies on coastal and marine SES.

No.	**Variable group** Identified conditions or processes in the system and the relevant information (in bullet points) obtained from Activities 2, 3, and 4	Related literature
A	**Social**	
1	Perception of ecosystems: • *Fish, coral reef, seagrass* variables and each of its perceived past trends and current conditions.	Cinner and Pollnac (2004); Slater, Napigkit and Stead (2013)
2	Impact of fishing activity: • *Traditional fishing*, *poison fishing*, *bomb fishing*, *squid/pelagic fishin*g variables.	Cinner (2011); Cinner et al. (2009)
3	Impact of other natural resource-based activity: • *Cattle farming, crop farming, fish farming* variables.	Bush et al. (2010); Lambin and Meyfroidt (2010)
4	Awareness of / Compliance to existing regulation: • *Marine zonings* variable. • Participant's comment about the illegality of destructive fishing practices at the time of the survey and *the 'ongko' customary rule* variable.	Cinner et al. (2012); Gezelius and Hauck (2011); Hauck (2008)
5	Socio-economic priorities: • *Household economic needs, availability of working time, the attractiveness of fishing over supplementary work* variables, which are related to the *safety and health during work, adoptability of the type of work, risks and uncertainties in fishing and/or non-fishing work,* and *labour time used for the work.)*	Ferrol-Schulte et al. (2013); Turner et al. (2007)
6	Perception of the legitimacy of rules & information: • *Law enforcement* variable. • Participant's comment about community distrust to law enforcers due to collusion.	Jentoft (1989); Satria, Matsuda and Sano (2006)
7	Norms: • *Non-fishing work* variable. • Participant's comment about fishing as a less undesirable work for the children of fishing parents and for fishers due to the high risk of fishing such as in health and safety and financial loss.	Cinner and Aswani (2007); St John, Edwards-Jones and Jones (2010)
8	Attitudes: • Participant's comment about the decision of the fishers in the village to establish and maintain informal surveillance for and/or enforcement of encroaching on Selayar's large fishing boats and destructive fishing activities.	Gelcich, Edwards-Jones and Kaiser (2005); Song, Chuenpagdee and Jentoft (2013)
9	Livelihood goals and priorities: • *Motivation to fish* and, *fish demand* variables. • Participant's comment about the various motivation of fishing such as for household subsistence, commercial purposes, and *recreational fishing.*	Cinner (2007); McClanahan et al. (2006)

No.	Variable group Identified conditions or processes in the system and the relevant information (in bullet points) obtained from Activities 2, 3, and 4	Related literature
10	Collaborative mechanism: • Participant's comment and interview responses about the existing community-based surveillance / patrol groups, fishing household members involved in several income-generating activities, cash lending support from relatives, and patron-client relationship in the sharing of fishing operational costs and revenue from fish sales.	Folke et al. (2005); Nkhata, Breen and Freimund (2008)
11	The flow of information about the social sub-system for social learning by the problem owner: • Participant's comment about how fishing methods were informally introduced to local Selayar fishers by the migrating/transiting fishers such as the destructive fishing methods.	Berkes, F. (2009); Berkes and Turner (2006); Weiss et al. (2012)
B	**Economic**	
1	Financial return, income: • *Household income* variables, which were also sourced from *fishing* and non-*fishing supplementary work*. • Participant's comments and interview responses about the influence of *household income* contributed by *fishing* and *non-fishing work* to the community's attachment to the work and the effort dedicated to the work.	Cinner, Daw and McClanahan (2009); Marshall et al. (2007); Marshall et al. (2013)
2	Commodity value, price: • *Fish sale price*, *costs of living* variables, which have a similar influence as *household income* (see above).	Cinner, Daw and McClanahan (2009); McClanahan, Allison and Cinner (2015)
3	Incentives: • *Fishing gear*, *fishing supplies*, and/or *fishing boat* variables. • Participant comment about fishing gear, supplies or boat that is supplied by fisher's patron that willing buy the fish or share sales revenue • Interview responses about the household's proximity to the raw terrestrial natural resource that can partly promote household decision to do non-fishing supplementary work such as *crop farming*, and *aquaculture*]	Jones et al. (2013)
4	Innovation and technology: • Participant's comment about the use of various strategies to improve fishing operations, such as the use of an underwater torch, improved compressor engine to supply air to fisher, and a bomb detonator. • Participant's comment about the use of mobile phone coverage to enhance coordination between fishers when fishing during surveillance. • Participant's comment about the need of storage and processing infrastructure for both fish catches and crop harvests, which is expected to improve fish shelf life to increase value, and to improve buyer waiting time to increase sales or avoid fish discards.	Moore and Westley (2011); Smit and Wandel (2006); Smith and Stirling (2008)
5	Market: • *Fish market* (in Selayar) and *local fish buyer/collector* (who resell fish either within or outside Selayar) variables	Cinner, JE et al. (2013); Robards and Greenberg (2007)
6	Fish supply, fish demand, fish value: • *Fish catch, fish buyer/collector, fish price* variables.	Cinner, JE et al. (2013); Coulthard (2008); Daw et al. (2012); Merino et al. (2012); Robards and Greenberg (2007)
7	Aquaculture demand: • *Seaweed farming* activity and *infrastructural support* decision variables. • Participant's comment about infrastructural support that was expected to re-enable fish farming activity.	Ahmed and Lorica (2002); Merino et al. (2012)
8	Harvest value: • Participant's comment about the preference of households that has close proximity to vast shallow intertidal areas (e.g., Barat Lambongan Village) to spend more time in seasonal seaweed farming for main income source instead of fishing.	Ahmed and Lorica (2002); Sheriff, Little and Tantikamton (2008)

No.	**Variable group** Identified conditions or processes in the system and the relevant information (in bullet points) obtained from Activities 2, 3, and 4	Related literature
9	The flow of information on the economic system for economic learning by the problem owner: • *Fish price* variable that was, based on participant's comment, perceived to be having a degree of uncertainty as it could be determined solely by the fish buyer/collector or based on the agreement between the fisher and the fish collector/buyer. • Participants' comment about local fish oversupply as a problem perceived partly due to local fisher or trader have lack of information about or limited access to the buyer beyond what they know in the proximity of living area, and/or due to the attachment of fisher only to a single of several local fish buyers.	Berkes, F. (2009); Berkes and Turner (2006); Weiss et al. (2012)
C	**Ecological**	
1	The condition of the higher and lower trophic species level: • *Fish* variable, which includes marine organisms that fisher target mainly of predatory finfish (e.g., *kerapu* or grouper), herbivorous finfish (e.g., *suliri* or yellowtail fusilier), invertebrates (e.g., sea cucumber, octopus, lobster, clam, squids), and primary producer plants (e.g., seaweed). • Participant's comment about the behaviour of fishers to target various fish species or groups given that a fishing trip may involve several methods of fishing. For example, fishers in the mobile lift net boat (*bagang*) also use handlines to capture other fish in addition to the targeted squid.	Folke (2004); Heithaus et al. (2008); Knowlton and Jackson (2008); Pinnegar, Polunin and Francour (2002)
2	Biogeochemical environment: • *Water quality, seasonal garbage standings,* and *oil pollution from boat* variables, which was – based on participants' comment – perceived to influence the identified marine Resource variables.	Moberg and Folke (1999); Talaue-McManus (2010)
3	Physical environment: • *Undesirable weather condition/storm*, and *predictability of weather season* variables, which is – based on participant's comment – affecting fishing trips.	Cullen et al. (2002); West and Salm (2003)
4	The flow of information about the state of the ecological system for social learning by the problem owner: • All of the identified Resource variables, the perceived past trends and current state, and the identified relationship between these resources. • Participant's comment about the mutual relationship between the fish that fisher target and the coral reef and seaweed areas where fishing occurs, and the consideration of dolphins as 'pests' (they were found to be damaging the traditional fishing nets) all based on participant's non-scientific observations.	Berkes, F (2009); Berkes and Turner (2006); Weiss et al. (2012)
D	**Governance**	
1	The legitimacy of the information gathered from the system: • The fishing community's divergent views, perception, values, or beliefs that were captured in the participatory activities (Activities 1,2,3 and 4) and, in some cases, acknowledgement by some of the representatives of government authorities that were also participating.	Cash et al. (2003); Jentoft (2000); Treffny and Beilin (2011)
2	Policy direction: • Participant's comment that expresses varying agreement to the establishment of some part of the Selayar Island inshore area as a district-level marine conservation area (or, *KKLD*). • *Marketing policy/intervention* variable (from the Decision variable group) which, based on participant's comment, was perceived to be necessary to increasing the quality or value and the sales of the harvested raw fish or crop resources. • Participant's comment about the need for a law or decree (part of the Decision variable group) that supports the legitimacy of village surveillance groups to increase community support to the existing marine patrol undertaken by government authorities.	Garmestani, Allen and Benson (2013); Weiss et al. (2012)

No.	Variable group Identified conditions or processes in the system and the relevant information (in bullet points) obtained from Activities 2, 3, and 4	Related literature
3	Resource-use regulation/rules: • Participant's comment about the understanding that blast fishing and cyanide fishing are illegal activities. • Participant's comment about the understanding that areas within a 0 - 4 mile radius from the coastal perimeter are designated as the operational areas for traditional fishers, which include small fishing vessels below ten GT.	Cinner et al. (2012); Glaser et al. (2010); Satria and Matsuda (2004)
4	Implementation of policy/rules/management tools that influence the behaviour of the problem owners: • *Marine zonings* and *community-based village surveillance groups* variables. • Participant's comment that acknowledges the varying levels of compliance by different fisher groups or villages with the existing marine zonings. • Several villages involved with the former coral reef management project still establish community-based village surveillance groups and some still actively patrol for infringement by boats above 10 GT in the village fishing grounds and for destructive fishing activities.	Ban et al. (2011); Ferse et al. (2010); Fitzgerald (2007)

5.6.2 The state variables associated with the problem

A number of state variables were defined based on the dominantly recorded Desired Future Trends (DFT) information during Round Two of problem mapping and the supplementary interview results. In Table 5-6, the state variable is associated with a particular trend that defines its normative influence on the problematic state of the examined livelihood system. In general, as shown in the annotated version of CLD 3 (Figure 5-32, Figure 5-33), the state variables (text in boxes) are internally regulated by one or more feedback loops (open circle arrow symbols) consisting of both self-reinforcing or self-balancing mechanisms (discussed further in Section 5.6.3).

Table 5-6. Identified state variables (Variable inside a box, Figure 5-32 & 27) associated with the topic problem and the normative justification. (Note: # = Based on the Trend perceived in the problem mapping FGDs [Appendix 12], ## = Based on supplementary interview).

No.	State variable	Normative criteria defined by stakeholder
1	Coral reef and other fish habitat condition	Desirable if gradually increasing in the future#, based on the perceived trend for *coral, fish seagrass, fish price, fish catch* and *population level* variable recorded in 70% of the FGDs (n=15).
2	Local fish population	
3	Fish catch	
4	Fish price	
5	Immigration and population	
6	Local fishing activity	Undesirable if gradually increasing in the future #, based on perceived trend for *traditional fishing, bomb fishing, compressor fishing* (including *poison fishing*), and *external fishing encroachment* variables recorded in 70% of the FGDs (n=15).
7	The fishing activity of households	
8	Destructive fishing effort	

9	Household savings / Net income / Disposable income	Desirable if gradually increasing in the future[#], based on the perceived trend for *income* variable recorded in 70% of the FGDs (n=15). Desirable if increasing [##]
10	Costs of living fulfilled (State of living)	Desirable if increasing [##]
11	Total household income	
12	Total financial burden (of households)	Undesirable if increasing [##]
13	Debt /loan burden	

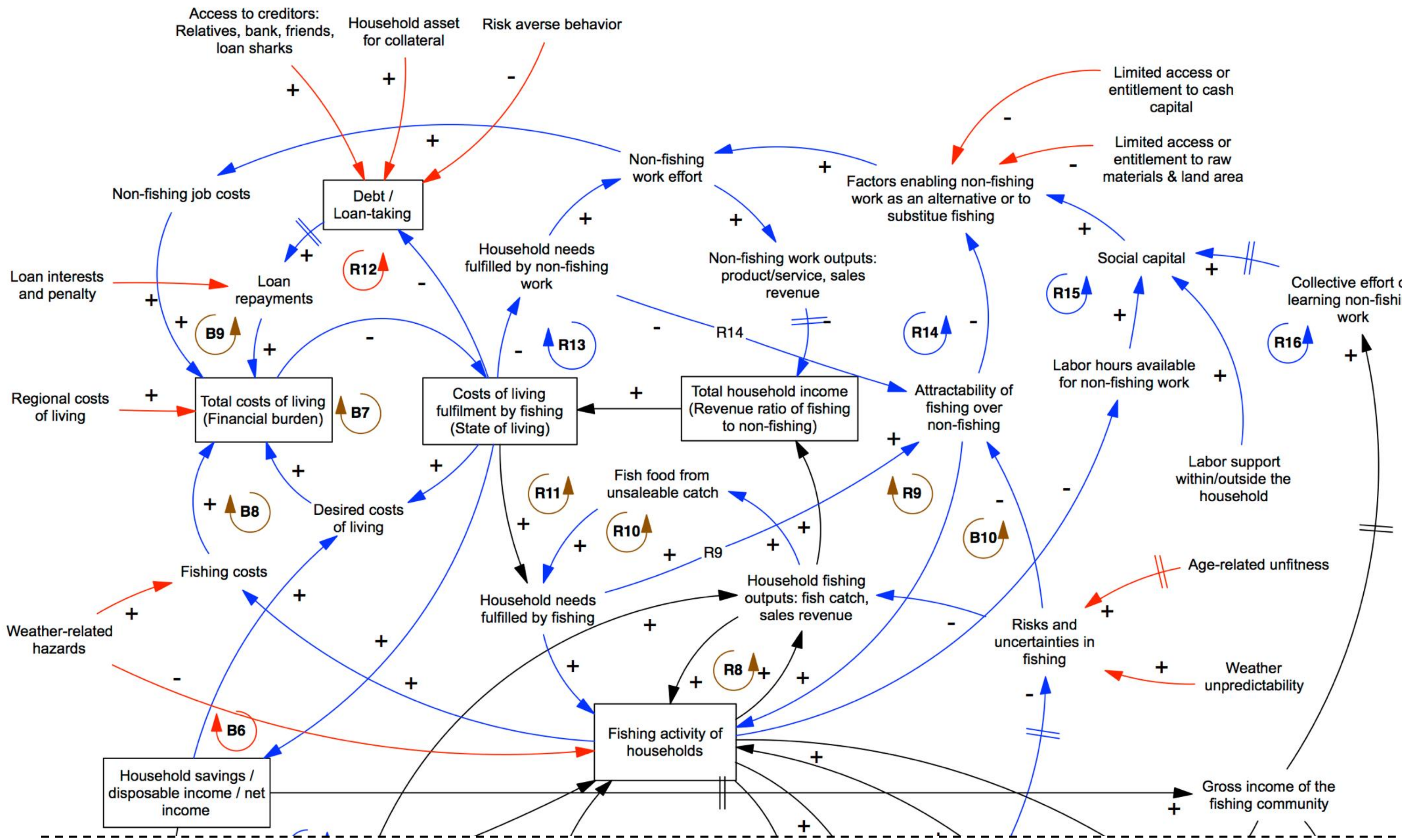

Figure 5-32. The top segment of a simplified version of CLD 3 (original: Figure 5-30 & 5-25) where variable names from problem-mapping FGDs are omitted. Variables in boxes are the state variables. Interactions occurring both at the household level (blue arrows) and broader (black arrows), and some identified influences outside the boundary of the observed system (red arrows). Feedback loops are indicated by the circular arrows moving in a clockwise or counter-clockwise direction (about loop: Section 5.2.1.1).

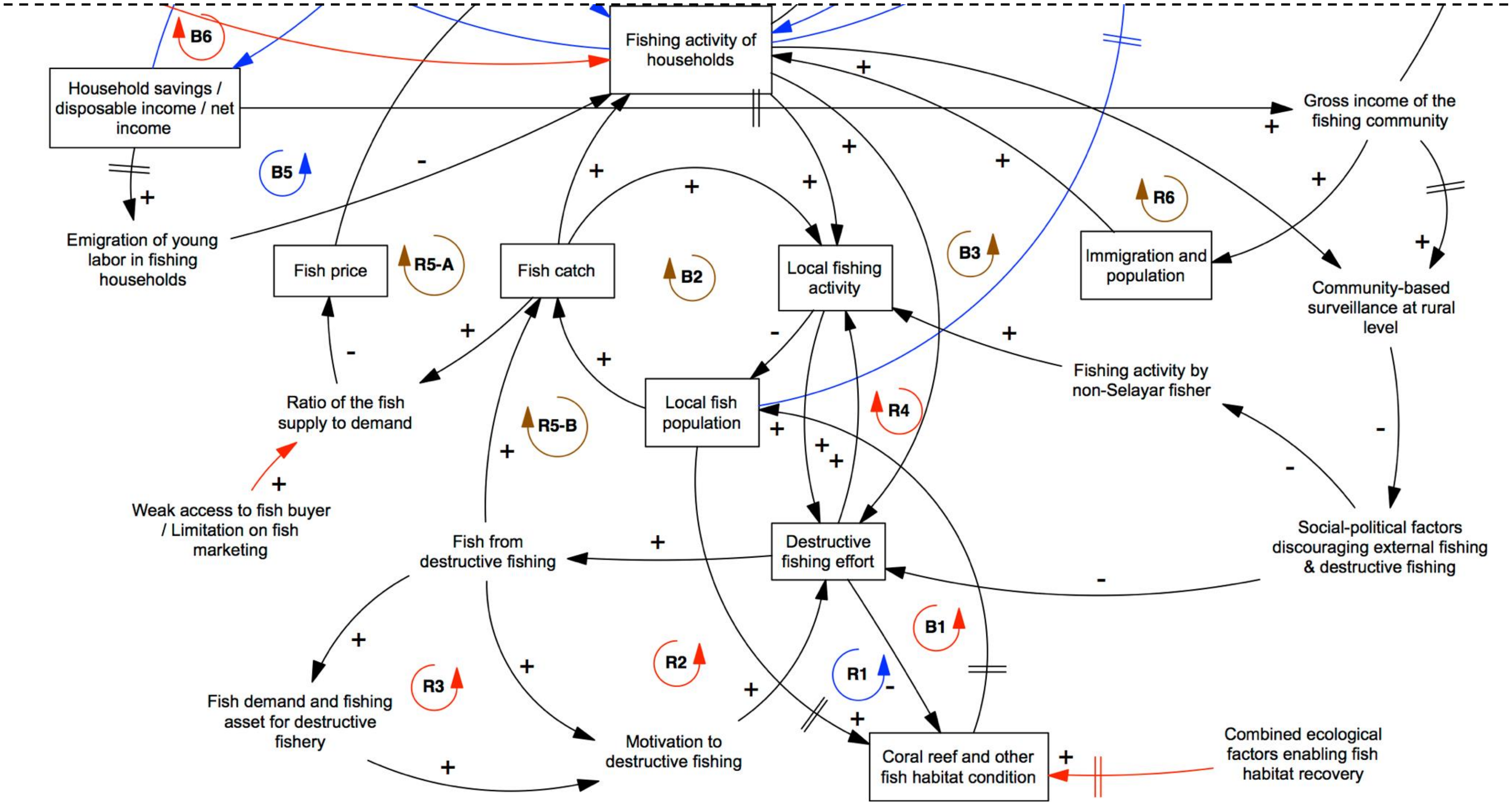

Figure 5-33. The bottom segment of the simplified CLD 3 that follows and has the same description as Figure 5-32.

5.6.3 Multiple feedback loops influencing the *state variables*

Figure 5-32 and Figure 5-33 indicate that the state variables of the modelled system are influenced by multiple structures of feedback loops (hereafter referred to as ‘loops’) of both reinforcing and balancing loops (hereafter abbreviated as R and B, respectively; for more information about loops, see Section 5.2.1.1). Each loop can directly or indirectly maintain the problem of “declining reef fisheries” (loop symbols coloured in red and brown, respectively), or alleviating the problem (in blue). The following subsections describe the ‘walk-through’ of the causal relationships traced in each loop and the influence of the loops in regulating the behaviour of the state variables.

5.6.3.1 Loops that are influencing the fish population, coral reef, and other fish habitats

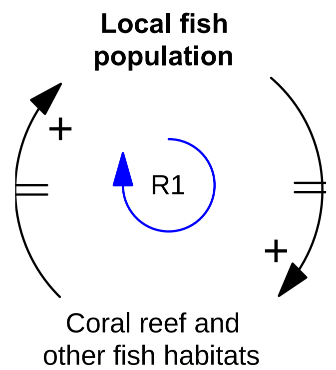

Figure 5-34. Loop R1 that influences fish and fish habitat.

In loop R1, the condition of local *fish habitats* such as the coral reefs and seagrass meadows determines the condition of the local *fish population* (Bellwood et al. 2006; Miñarro et al. 2016). The diversity and abundance of particular fish species can also determine the maintenance of the complexity and structure of the fish habitat (Gratwicke & Speight 2005). Hence, R1 is a desirable loop for the problem owners as it sustains natural resources important to livelihoods. Yet, in real life, there is a delay given that the recovery of natural resources occurs slower than the rate of harvest and is not an infinite process. That is, the growth of each resource is ultimately limited by the carrying capacity of the ecosystems.

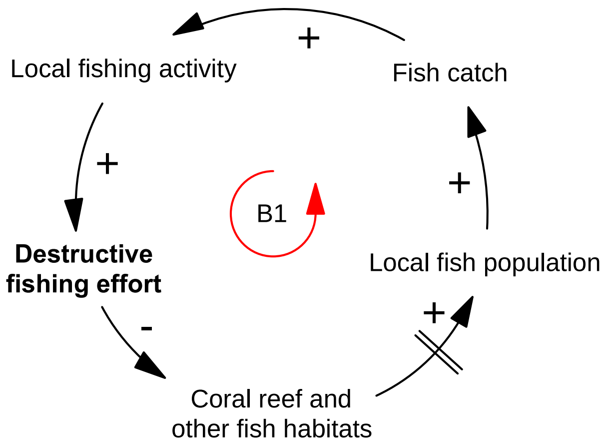

Figure 5-35. Loop B1 that influences destructive fishing effort.

In loop B1, *destructive fishing* results in physical (i.e., blast fishing) and/or chemical damage (i.e., cyanide fishing) to *fish habitat*, which may intensify in proportion to local capture *fishing activity* (i.e., fisher overcrowding). Local fishing activity can be augmented by the amount of *fish caught* in the past and the fish available in the wild (also influenced by loop B2: Section 5.6.3.2). Therefore, loop B1 is undesirable as it is weakening loop R1. In this case, damaged habitat can disrupt the ecosystem's capacity to regenerate the population of both the targeted and non-targeted fish species. This, in turn, can reduce the abundance of certain fish species that maintain the complexity of the fish habitat. But it has been acknowledged, both by the problem owners and in the expert literature, that destructive fishing is an activity that can be mitigated by social and/or political factors promoting behaviour change (Veríssimo 2013), as well as increased surveillance and law enforcement (Crawford et al. 2004).

5.6.3.2 Loops influencing local fish population and local fishing activity

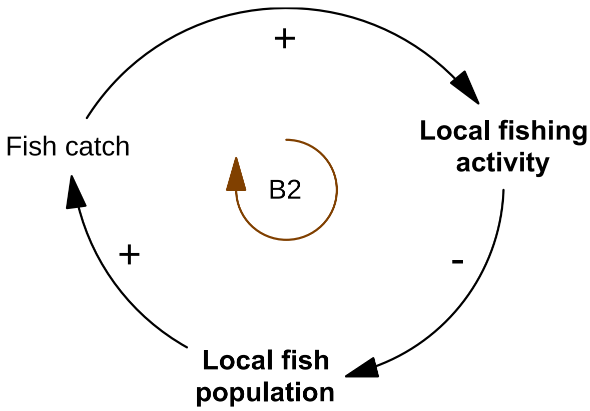

Figure 5-36. Loop B2 that influences local fish population and local fishing activities.

In loop B2, *fish species* is the input to *capture fishery* livelihoods in rural Selayar. The improving condition of *fish species population* can determine higher *fish catch* in terms of abundance, mass and/or price. Past or recent experience in harvesting wild fish can stimulate the community to maintain *fishing activity* motivated by economic (e.g., saleable fish, food for subsistence) or social (e.g., maintain cultural tradition, the perception of resource availability) factors. Loop B2 is potentially undesirable, particularly if overfishing is already taking place, which is when this loop outperforms the recuperation of fish condition in loop R1.

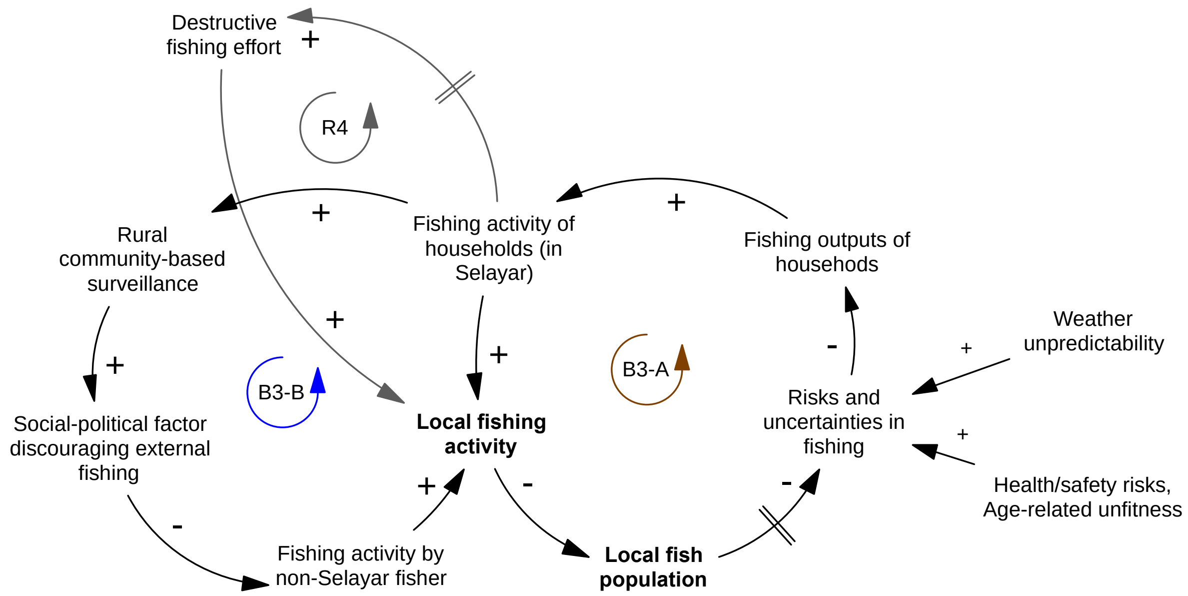

Figure 5-37. Loop B3-A, B3-B that influence local fishing activity and fish population.

Loop B3-A is a structure that extends loop B2 whereby episodes of *fish harvesting* can also partly shape a fisher's judgement of a declining wild *fish population*. The perceived past decline of *wild fish* underpins increasing *risks to livelihood* alongside other recorded external factors such as increasingly *unpredictability of weather* (e.g., problem mapping results: Section 5.1.2.3) and fisher's *age-related unfitness* (e.g., interview results: No. 15, Q19; Appendix 16). Accordingly, these risks act as an inhibiting influence on the *fishing activity of households* that contribute to fishing in the local area. Despite having the potential to put a limit on fish extraction (i.e., B2 dominance over R1), an inherent delay in the influence of B3-A may exist. This may influence the way fishers gauge ecological change – which is largely based on the fish catch that they harvest. In turn, this leads to years of delay in the perception that fish populations are declining. Therefore, this loop is potentially undesirable considering that it constitutes 'slow' feedback where fishers are unlikely to be able to respond or cope promptly to a resource crisis (i.e., overfishing) when it occurs.

In relation to loop B3-B, the *local fishing activity* identified in this assessment is mainly associated with the rural capture fishery activity using boats operating largely in inshore areas approximately 0 - 4-mile radius from the coast. Based on the household survey conducted on Selayar Island by A. Lindsay (Section 3.6.6.2), more than half of the boats used by the sampled fishing households (n=152) were traditional boats, such as *sampan*, *jarangka*, and *jolorro* which have an average engine horsepower of 6, 7, and 36, respectively. Furthermore, Selayar capture fishery statistics in 2014 reported that Selayar fishers used a diverse range of fishing gear such as *jaring angkat* (lift nets), *jaring insang* (gill nets), various *pancing* (handlines), *perangkap/sero/bubu* (traps), various *pukat* (purse seines), and spears and spear guns. At the same time, within the informally claimed 'village fishing grounds', some Selayar fishers/fishing groups employed *destructive* methods (i.e., cyanide fishing, blast fishing) (see loop R4) and the larger-capacity *non-Selayar fishing boat* was also operating within the grounds. Some villages perceived the activity of the latter as an infringement or violation and responded with *community initiatives to patrol their fishing grounds* undertaken while they were conducting fishing trips. Hence, loop B3-B is desirable as surveillance, to some extent, and can deter the activity *of non-Selayar fishers* and destructive practices and thus reduce *local fishing activity* to allow resource recuperation (loop R2 dominating).

5.6.3.3 Loops influencing *fish price* and *fish catch*

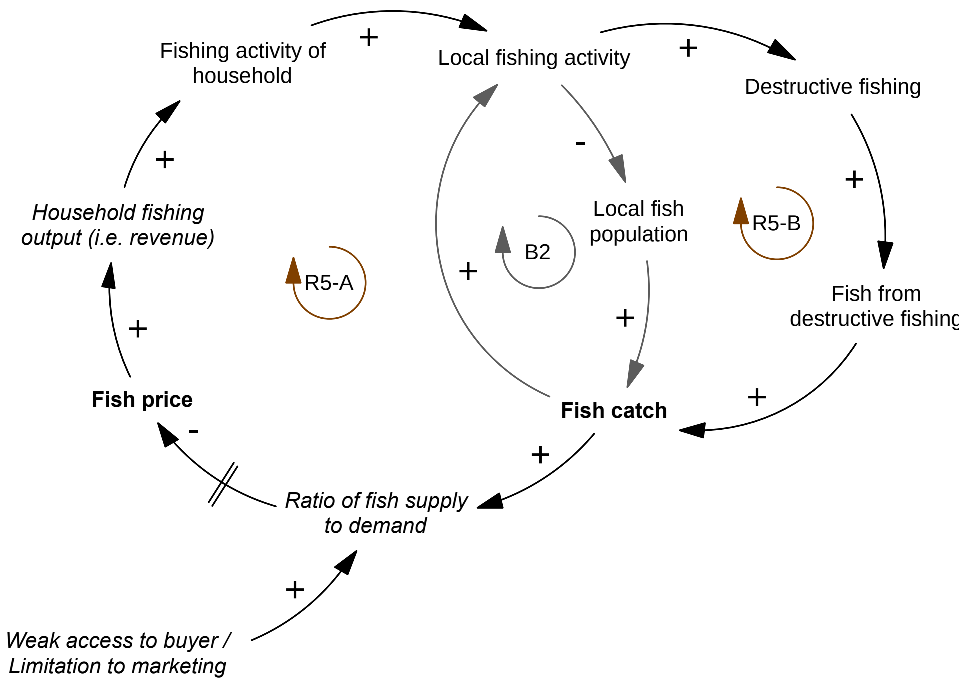

Figure 5-38. Loop R5-A, R5- B that influence fish catch and fish price. The model also includes non-state variables (Hereafter, presented as text in italics).

In loop R5-A the change in *fish price* proportionally affects *fishing output* such as revenue. Income from fishing is among the factors that can maintain or motivate a *household to conduct fishing* (also other loops: Section 5.6.3.5) and subsequently intensifies *local fishing activity* contributing to the increase of fish catch landed locally (see also loop B2). *Fish catch* proportionally influences the ratio of local fish supply to local fish demand; which can, however, inversely affect the *fish price*. In this case, a positive ratio value can trigger local fish oversupply which was supported by the participants' claim of past events of price drops during higher-than-normal fish harvest periods (seasons with desirable weather for fishing trips). This was found to be exacerbated by fisher's limitations in terms of fish marketing and/or available raw fish buyers on the island. In loop R5-B, *domestic fish catch* can also include 'trash' *fish from destructive fishing*. Low-value fish catch that is 'rejected' by exporters, such as fish with noticeable tissue damage from blasting or sickness from poisoning adds to unsaleable local fish landings. Loops R5-A and B can be undesirable if intensified by the added costs of fishing, leading to a population decline in fish (loop B2). At the same time, the assurance that increased resource input increases revenue is constrained by limited access to the *fish buyer* (for loop R5-A) and/or a trading mechanism that tends to be very selective of fish type (i.e., live reef fish food trade species).

5.6.3.4 Loops influencing destructive fishing effort

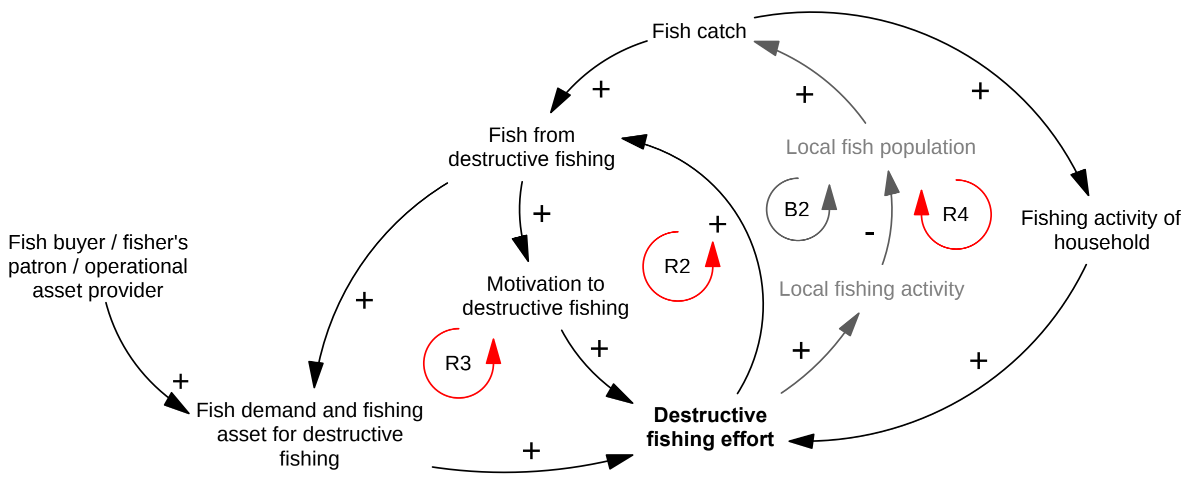

Figure 5-39. Loops R2, R3, and R4, which influence destructive fishing effort.

Loops R2, R3, and R4 relate to the maintenance of *destructive fishing effort* that is influenced by previous experiences of harvesting high-value fish species (loop R2), fish sales certainty, and operational asset provision (e.g., blasting and cyanide supplies) from the patron (loop R3), and trip cost reduction from efficient catch method (loop R4, extending B2). The loops are undesirable as they intensify local fish exhaustion (loop B2) and may also cause irreversible degradation of the fish habitat (loop B1, shown previously). Loop R3 is externally driven by the destructive *fisher's patron* (i.e., patron-client relationship: (Miñarro et al. 2016)) who can act as both fishing asset provider and sole fish buyer.

5.6.3.5 Loops influencing local *immigration* and *population*

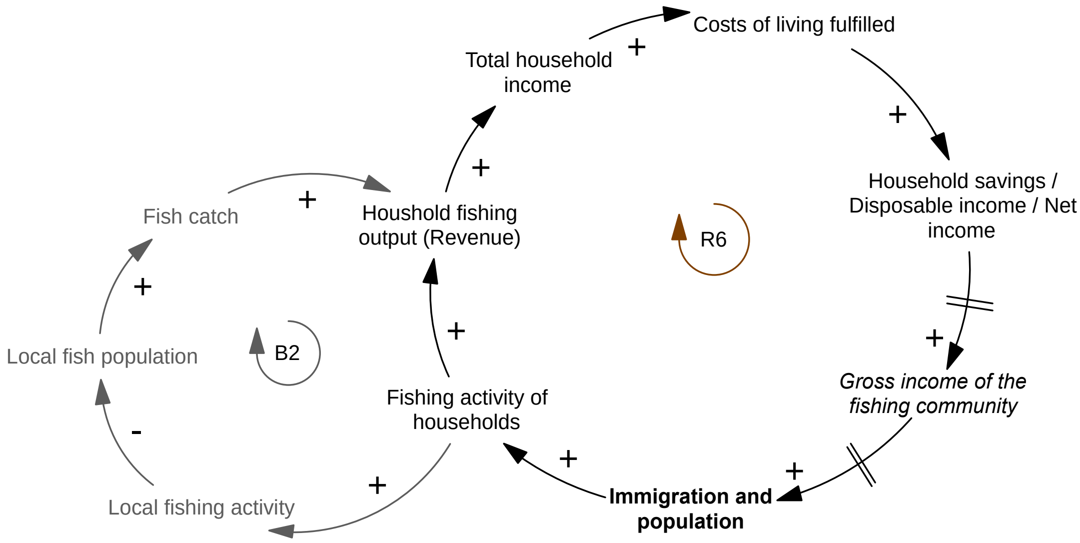

Figure 5-40. Loop R6 that influences immigration and population.

In loop R6, immigration of fishers and the resulting increase in the fishing community population positively change the number of fishers in the community, and, subsequently, *fishing households*. The *revenue* from raw fish sales maintains the household's income stream, which is used to fulfil *costs of living*, which, in times of financial surplus, can be used as *savings or disposable income*. This financial state of the households proportionally defines the *gross income of the fishing community*, which at some level can be an attractor for immigrant fishers and existing domestic working-age residents who might elect to become fishers in the Selayar region. The loop can be undesirable if it augments loop B2 at an intensity that overcomes R1's dominance.

5.6.3.6 Loops influencing the fishing activity of households

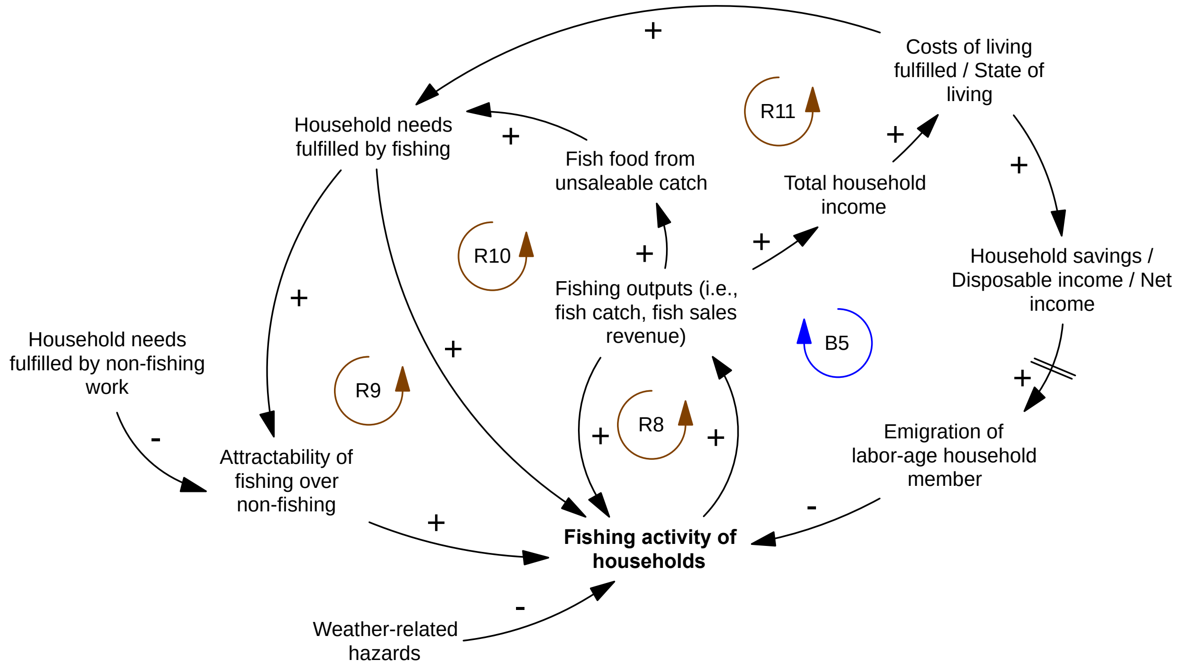

Figure 5-41. Loops R8, R9, R10, R11, and B5, which influence the fishing activity of households.

In loop R8, *fishing by households* can be a 'tradition' when previous generations of the family have relied on fishing for a livelihood. Extending loop R8, in loop R10, *fish catch* – particularly unsold ones – can support the dietary *needs* of the household. Furthermore, a similar positive influence on fishing effort is displayed in loop R11 whereby the monetary *output of fishing* (i.e., sales revenue) supports household *income* and can subsequently cover a portion of the *costs of living*. Fishing *revenue*, to some extent, determines the *state of living* by providing for household *needs*. In addition, fishing can be motivating for recreational reasons (i.e., *recreational fishing* variable: no. 9 under Social, Table 5-5).

Loops R10 and R11 are considered desirable given the aforementioned potential of 'fulfilling two needs in single effort' of fishing. Extending these loops, as shown in loop R9, the *needs fulfilled* partly shape *the attractiveness of fishing* over benefits from other non-fishing income generating activity in the household. This comparative consideration partly shapes the allocated amount of labour effort that fisher or household would spend in fishing over another activity. For example, in situations where it is feasible to obtain more income from non-fishing work, a number of fishers were willing to consider allocating more labour effort to non-fishing substituting fishing as the main income source (i.e., interview no. 7, 11, 13-15, 18 under Q17, Q18, Q20, Appendix 16).

Similar to loop R6; loops R8, R9, R10, and R11 can be undesirable if they escalate and augment the influence of loop B2 and undermine R1. Yet, maintenance of fishing by household is limited by exogenous factors, such as *extreme weather events* that can directly restrict fishing trips that shape the seasonality of the activity. Internally, for fishers/households that have experienced higher income from *non-fishing activity* for more cost-effective work at a lesser health risk than fishing (i.e., response no. 11, 15, Q19) it is desirable to reduce fishing effort (i.e., responses of Q17, Appendix 16) or stop fishing (i.e., interview responses of Q18, Appendix 16). Yet, despite having additional occupational skills, some fishers with an emotional/psychological attachment to fishing may be less flexible in regard to adopting the aforementioned preferences (e.g., response no. 12, 15, Q19).

In loop B5, the *revenue* from *household fishing activity* contributes to the total *income* of the household that may include revenue from non-fishing. In situations where the total *income* is in surplus to the expected *costs of living*, fishers/households can save money, or, on the other hand, reduce debt. The maintenance of savings might be used by the household to finance the working-age household member to *emigrate* from Selayar for educational or work purposes; however, this may need to be preceded by a period of accumulating savings up to a particular threshold. This loop is socially desirable with respect to the problem owner, given that migration can be favourable to some fisher parents who do not expect their children to work as fisher after high school (participant's comment: Barugaiya fisher, FGD Round Two, 2016/08/02, Table 11 of Appendix 12) Additionally, FGD participants largely perceived that further increases in local fishing were undesirable (unsustainable) and hence did not represent a good future for their children (i.e., see the trend for *traditional fishing* and the associated bimodal response, *Section* 5.1.2.3). These negative perspectives on fishing might also be influenced by the amalgamation of the aforementioned increasing risks (i.e., weather hazards and uncertainty as well as health risks [loop B3-A], the lack of control in obtaining a desirable fish price [loop R5]), and perceived depletion of local fish populations (loop B10, Section 5.6.3.8). As oppose to loop R8 to R11, loop B5 is desirable as it can potentially lessen the influence of B2 and thus allow R1 to dominate.

5.6.3.7 Loops influencing local household savings / net income and financial burdens

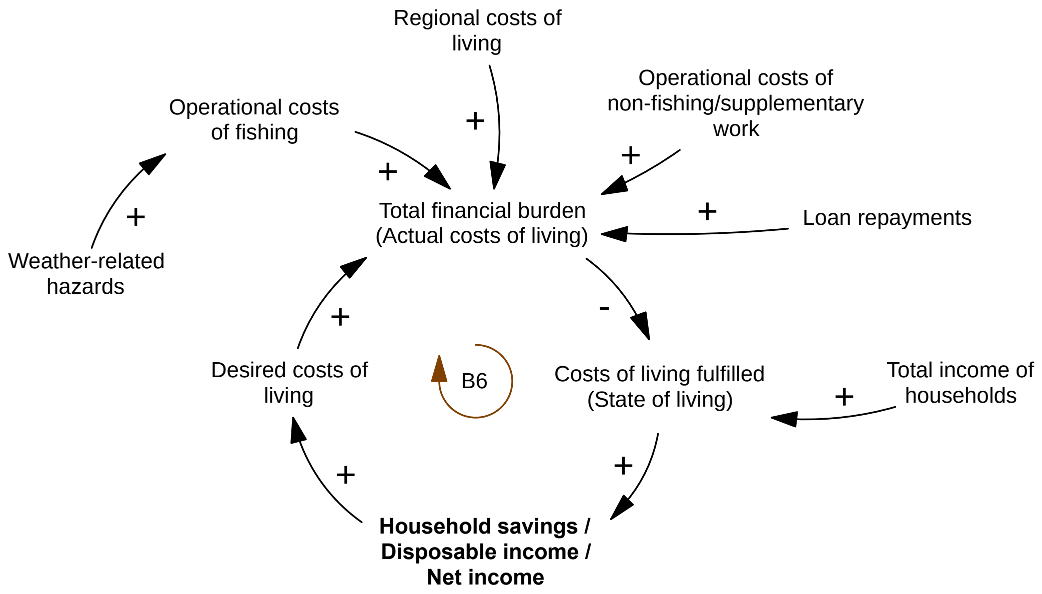

Figure 5-42. Loop B6 that influences household savings/net income.

In loop B6, the level of *household savings (net income)* influences the expected subsequent spending can it serve as information for fisher/household to gauge their financial capacity and to set their desired costs of living (or, the 'wants'). Household needs are juxtaposed with any existing financial burdens or responsibilities (or, the 'needs') such as the price of basic needs, cost of business operations, and/or loan repayments that define household's *actual costs of living*. This financial burden negatively influences the *state of living* - reflected by the capacity to maintain savings goal or to avoid deficit; which therefore makes the loop maintenance as an undesirable circumstance.

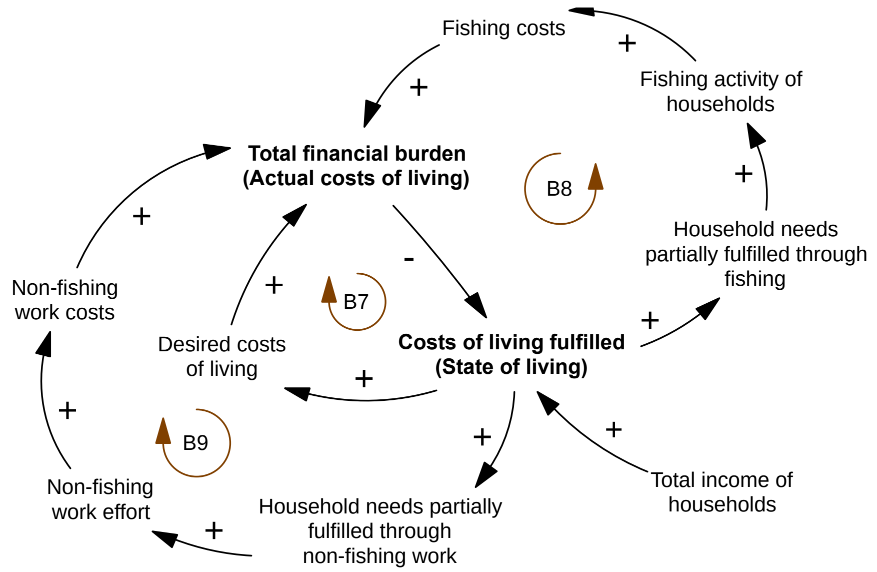

Figure 5-43. Loops B7, B8, and B9, which influence the fulfilment of costs of living as a measure of the state of living of fishing households.

Loops B7, B8, and B9 can each influence the *total financial burden or costs of living.* In loop B7, these costs depend on the interplay between the actual versus desired cost of living, and financial burden. Fulfilment can proportionally shape fisher/household's internal motivation to limit expenditures (*desired costs of living*) in addition to the influence of savings (loop B6, Figure 5-42). Therefore, loop B7 can be endogenously desirable as a spending goal can be set to avoid an undesirable financial state in the near future. However, the suppression of financial responsibility can still be overridden by externally promoted influences that increase chances of the deficit, such as price inflation, and/or internally, such as unexpected business costs (loop B8, B9) or pre-existing debt burden (loop R12).

In loop B8, the *total financial burden* also includes the *costs of capture fishing activity*. The costs increase parallel to the level of effort undertaken to harvest fish. The *effort for fishing* is partly motivated by the level of the household financial *needs* (as in loop R11, Figure 5-41) *fulfilled from past fishing activity*. Similar to loop B7, this loop can be undesirable particularly when fishing costs and/or fishing activity are being reinforced internally such as by loops R8, R9, R10, and/or R11 intensify). This multiple feedback influence can be difficult to interrupt particularly when fishing is the only activity that can satisfy the commercial and subsistence motive. Additionally, the *fishing cost* in loop B8 can be augmented directly by weather-related changes owing to the increasing fuel usage for longer trips or other weather-related operational costs (e.g., equipment damage, injuries).

Loop B9 is similar to B8: the additional *costs to operate any non-fishing/supplementary job* in the household can add to the *total household financial burden*. The *non-fishing operational costs* also increase in parallel to the *non-fishing effort* that the household might take up, which might be aiming to reduce the financial burden by undertaking non-fishing activities (loop R13, Section 5.6.3.8).

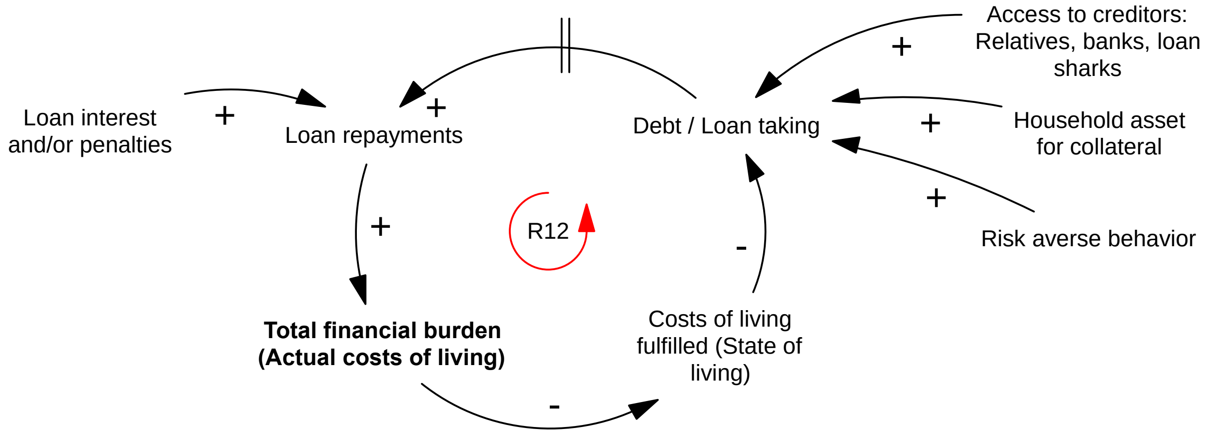

Figure 5-44. Loop R12, which influences the total financial burden of fishing households.

In loop R12, the costs associated with *loan repayments* also add to the *total financial* burden. The level of loan repayments could be influenced exogenously by *the rate of interest or penalty* that predominantly decided by the lender if the penalty applies in the loan arrangement. Internally, repayment is set proportionally by the total of loan principal borrowed or any existing debt that can also include accrued interest. The debt can further increase as fisher/household take more frequent or larger cash loans in order to avoid or maintain a deficit state (e.g., see interview responses of Q29, Appendix 16). In the viewpoint of a 'low' *state of living*, the financial hardship, such as deficit, can be prolonged when the loops that seek to promote living expenditure at the cost of its fulfilment (e.g., loops B7, B8, B9, and R12; this section) has a dominating influence over loops that maintain or generate income (e.g., loops R8, R9, R10, and R11 [section 5.6.3.6], R13 [section 5.6.3.8]). Ultimately, loop R12 is undesirable as it embodies debt accumulation that may lock in household debt.

5.6.3.8 Loop influencing total household income, and non-fishing work output

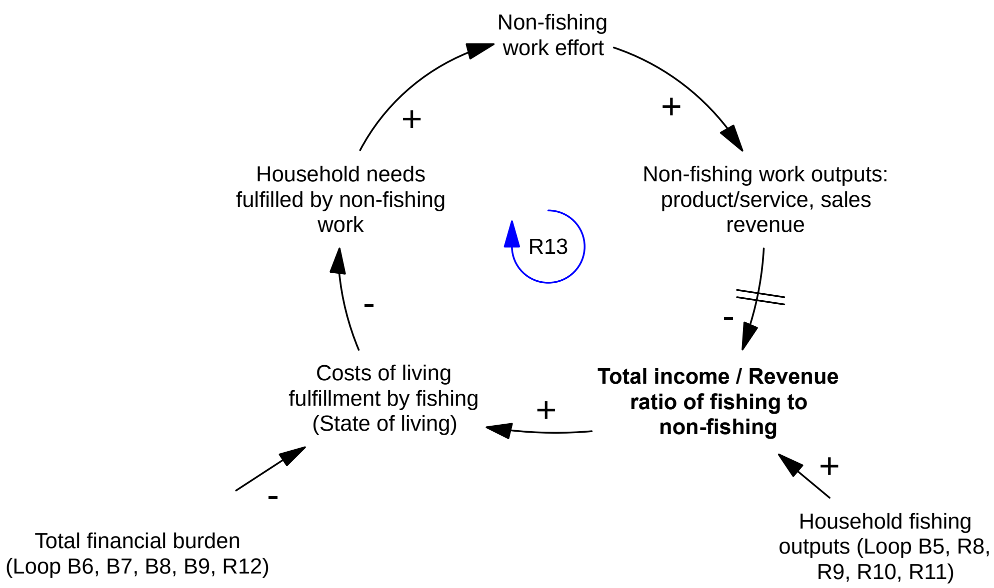

Figure 5-45. Loop R13 that influences the total income of fishing households.

In loop R13, *the total income* of a fishing household can also be sourced from supplementary *non-fishing activity* (related: Non-primary livelihood activities: Table 4-2; Supplementary work: Response of Q11, Q14 in Appendix 16) in addition to fishing (related loops: Section 5.6.3.6). The *revenue from non-fishing activit*y changes proportionally to the profit gained from the sales of products or services as an outcome of the amount of effort dedicated to non-fishing efforts. However, there is a risk of delay in generating the alternative revenue, particularly if the activity required substantial time and resource investment like that required in agriculture (e.g., cattle farming, crop farming; ±45% of the surveyed fishing households, n=152, Appendix 17) where the saleable product is seasonal. Similar to fishing, *revenue from non-fishing* that relieve past financial burden partly motivates fisher/household to maintain or improve the *non-fishing effort*. In association with the topic problem, loop R13 is desirable as it can potentially negate over-reliance to income generation by fishing (loops in Section 5.6.3.6), suppress local fishing intensification (loops in Section 5.6.3.2); and thus, can promote recoverability of the already depleted fish resource or degraded fish habitats (loops in Section 5.6.3.1).

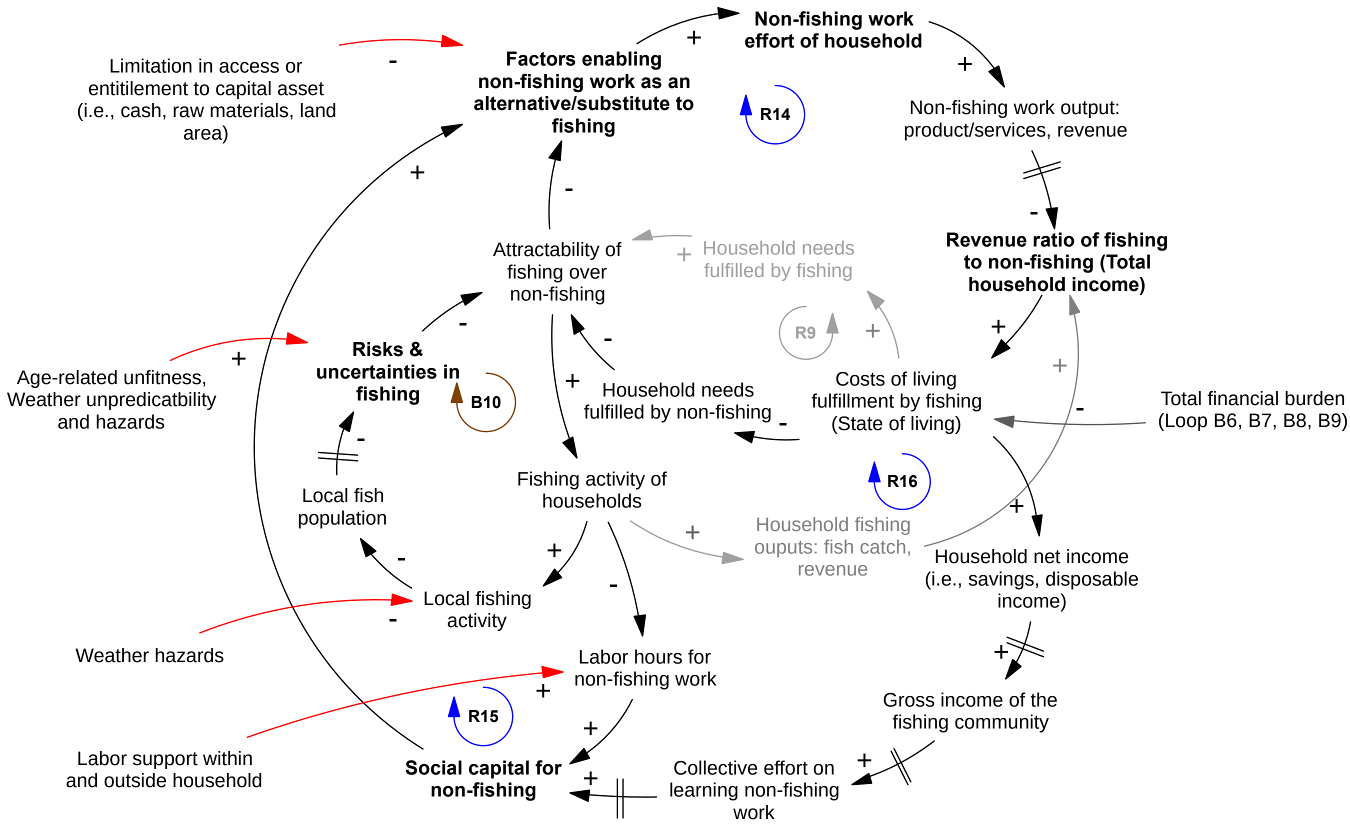

Figure 5-46. Loops R14, R15, R16, and B10

Loop R14 extends the causal link in loop R13 whereby *non-fishing effort* is also dependent on a *set of enabling factors* and includes access or entitlement to the capital assets required. These may be limited, or depend on support external to the household (e.g., access to raw resource and supporting equipment or tools [variables no. 3, 4, 7 of Economic category] in Table 5-5; cash capital [interview no 3. for Q14; no.11, 13, 15 for Q19], raw material [interview no. 17 for Q-22, 13 for Q24] in Appendix 16). Moreover, there are also factors internal to the household that may demotivate *non-fishing effort* (i.e., supplementary occupation) from the influence of *the attractability of fishing over non-fishing*. In this interaction, the allocation of non-fishing effort would be increased if the *non-fishing output* is able to fulfil a larger portion of *the household needs* compared to the fishing outputs (e.g., interview no. 7, 15 for Q19, no. 18 for Q24; no. 13, 15, 18 for

Q25; in Appendix 16). To offset *the costs of living*, expenses are generally substracted from the *total income* generated by all household members or from fishing and other supplementary work (if any). Similar to loop R13, the revenue and other outputs of non-fishing work are influenced by the level of *effort for non-fishing* activity and loop R14, which is a desirable loop as it improves the *state of living*.

In loop R15, another factor that can facilitate households to engage in a non-fishing activity is that of *social capital*, which includes the available *labour time* for the alternative or supplementary work. But for those fishers who are either primary income producers or household members, more labour time can be allocated in exchange for the reduction of *fishing labour*. As in loop R14, the reduction should be preceded by the reduction of fisher/household member's *attraction to fishing over non-fishing work*. When household income reliance on fishing is high (i.e., loop R9 dominates R14), a household can obtain internal *labour support* from a member of the household, such as the fisher's spouse, or externally from the community. The influence of loop R15 is desirable as it directly reinforces loop R14, which is also the case for loop R16 – this is explained in the next paragraph.

In loop R16, also an extension of loop R14, *the fulfilment of costs of living* can be indicated by a financial surplus in the form of *household savings or disposable income*. To some extent, when a number of households can maintain and/or increase their savings, *the gross income* of the community might also be expected to improve. This can be mediated through actions that are either collective (i.e., households contributing to gross community income, rural savings, or loan cooperatives) or independent (i.e., funding for tertiary education of a member within a household), which improve the social capital of households/community. It was identified that knowledge and skill development determine a fisher's adoption of new or existing non-fishing livelihood activities (interview no. 16 for Q19, 20 for Q22, 2 for Q25; in Appendix 16). There is a delay, however, since learning is not an instant, but more of a cumulative process.

Counteracting loop R14, in loop B10, *the attractiveness of fishing over non-fishing work* can be negatively influenced by the increase in perceived *risks and uncertainties associated with fishing* (also augmented by loop B3). The risks associated with fishing can escalate as *fish populations* decline in local fishing grounds and as the *fishing activity of households* increases. However, there is delay due to fishers' affirmation of the *local fish population* that emerged as a non-immediate process because it requires episodes of fish harvesting to allow fishers to reflect changes based on fish catch history. Finally, the *fishing activity of households* that decrease fish populations increases parallel to the attractiveness of fishing over non-fishing. The delay makes loop B10 undesirable as it underlies resource users' failure to recognize the signals of resource exhaustion. On the contrary, maladaptive responses tend to be maintained given the dominating loops that maintain overfishing (i.e., loop B2), financial dependence of fisher/household to fishing (i.e., loops R8, R9, R10, and R11), and the ecosystem's capacity to regenerate fish (i.e., loop R1) particularly when fishing is the sole income-generating activity. Yet, loop B10 can further reduce fisher/household attachment to fishing (i.e., willingness to shift out from fishing: interview no. 7, 11, 13, 14, 15 for Q18, Q19; in Appendix 16). This may be attainable in the presumption that non-fishing work is equally or more lucrative than fishing (i.e., loop R14 dominate R9); improved social capital (i.e., skills/experience, available labour time [loop R15], labour support [loop R16]) and access to capital asset;.

5.6.4 Archetypical system structures that are driving the *declining reef fisheries problem*: Path-dependency of social-ecological traps

After exploring the loops identified in the previous section, several archetypical system structures (presented as CLDs) were identified. Conceptually, each archetype displays a distinctive combination of reinforcing and balancing feedback loops that ultimately drive undesirable states of social/and or ecological variables (see Figure 5-30, Figure 5-31). Overall, these archetypes demonstrate the clusters of causes that self-reinforce the mismatch between the maintenance of the livelihood activity and the livelihood resources, which therefore confirm a social-ecological trap (SET). Furthermore, the hypothesised dynamics generated by these archetypes correlate with some of the perceived past trends of the state variables (presented as BOTGs, about: Section 5.2.1.4) as well as some expected future trends. The archetypal structure and behaviours are discussed in the following subsections.

5.6.4.1 Archetype 1: Fixes that fail

The 'fixes that fail' condition (see CLD in Figure 5-47) involves problem symptoms that demand that the problem owner provides a solution. Several immediate fixes were implemented, which alleviated the problem symptom (loop symbol in blue). However, during implementation of the fixes, a set of unintended consequences was generated at a slower rate (loop symbol in red). These consequences reinforced the problem symptoms, whereby problematic trends in the state variables, such as household debt, fish population size, and income from fishing are maintained.

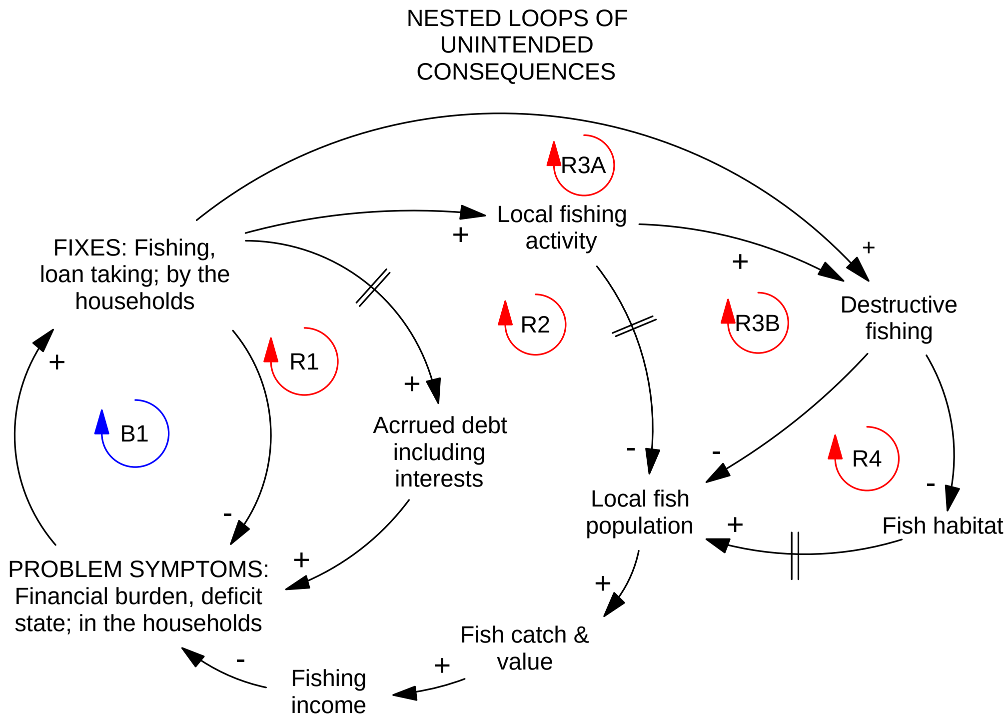

Figure 5-47. The identified “fixes that fail” archetypal structure.

Furthermore, the hypothesised dynamics of this archetype were found to be consistent with the dominant trends perceived by the problem-mapping FGD participants (Table 3a, Appendix 12). As shown in Box A in Figure 5-48, the increasing pressure of household economic needs (including deficit) promotes the adoption of ‘quick fixes’ such as those related to filling gaps in fishing income by increasing loan exposure, which is compounding problematic trends such as increasing household debt in the face of decreasing local fish populations. However, as shown in the hypothetical BOTG maintained by the feedback loops (Box B in Figure 5-48), the financial fixes are temporary since the underlying problem (less fish) worsens, and hence attempts to pay off debt (e.g., from past loans for fishing) become progressively more difficult, with an increased risk of failure as time progresses.

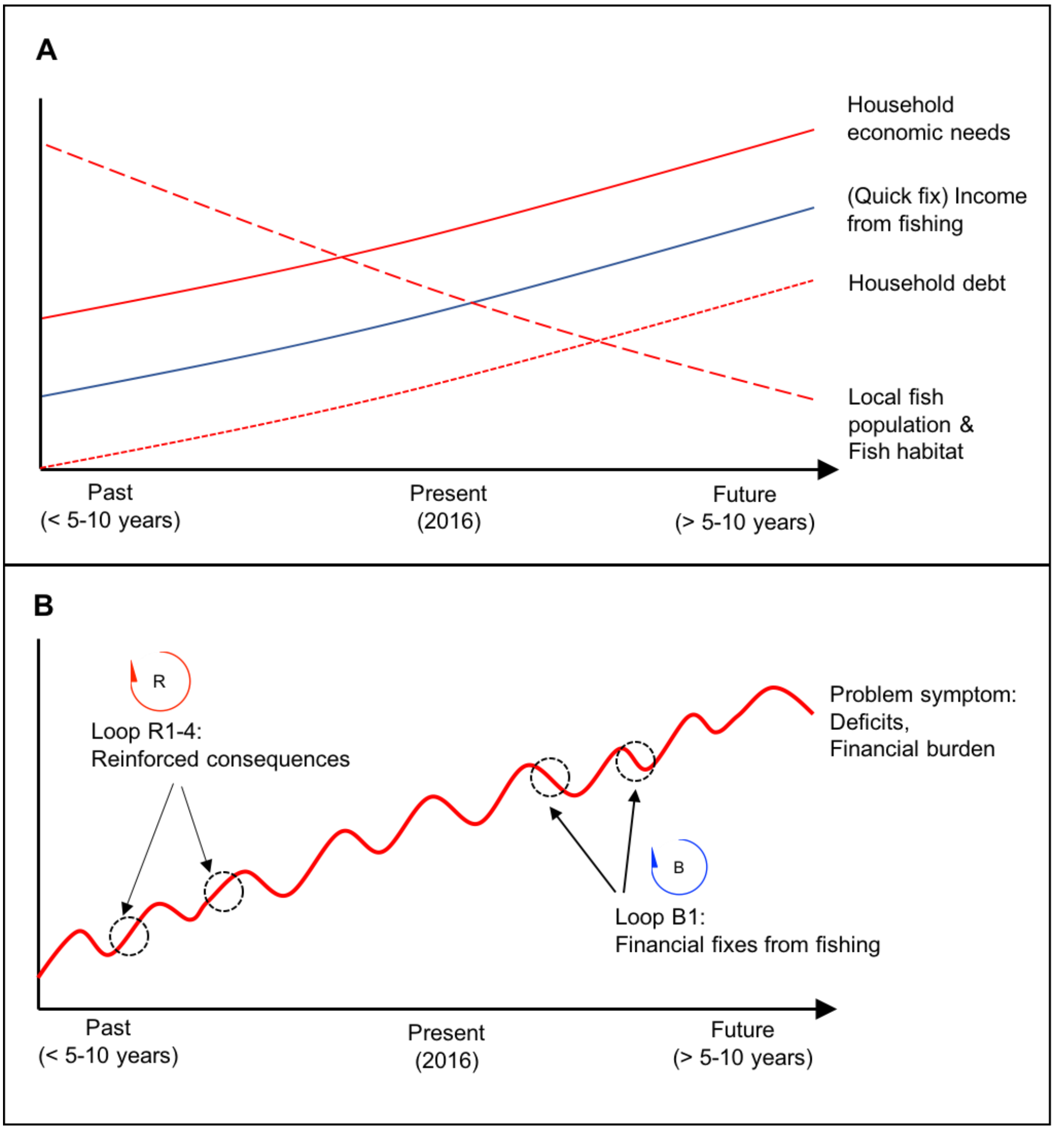

Figure 5-48. BOTG associated to the "fixes that fail" archetype.

The 'fixes that fail' case maintains the socio-ecological trap (SET) as the problem stakeholder's effort to provide solutions constantly fails (Senge 2006). The SET intensifies further when the stakeholder does not try a different approach and instead increases the scale of the previously adopted solution (e.g., increases loans with additional loans and, at the same time, fishing effort) (Senge 2006). Informational solutions such as improving the ability of the problem stakeholder to recognise that the fix is not solving the problem, and/or that the potential unintended consequences may work to reduce the tendency to add more debt. However, for the small-scale fishing households. Here, I would argue that the 'fixes that fail' situation is a largely impossible dilemma for the problem owner in Selayar. Since livelihood resource supply and demand are largely beyond the control of the fisher or households (e.g., suppressed demand due to restricted buyer and limited marketing capacity, information about the fish condition or recovery rate is not available or unknown to the fishers, and regulation of harvest activities is weak or inexistent at the level of community), achieving a fundamental change to the problem may require an externally-driven leverage points (Meadows 2009, p. 145) that can help fishers/household to restructure and diversify their livelihoods to help them reduce their livelihood dependence by extracting natural resources (Cinner 2014; Finkbeiner 2015).

5.6.4.2 Archetype 2: Shifting the burden

The second archetype, 'shifting the burden' (see CLD in Figure 5-49), also begins with a problem symptom(s). The problem owner can reduce the symptom with a symptomatic solution(s) (see loop B1) and/or a more fundamental solution (see loop B2). However, when the symptomatic solution is implemented, it generates side-effects that reduce the ability for (or diverts the attention from) implementing the fundamental solution required (see loop R1, R2). Hence, over time, more symptomatic solutions are implemented, with the problem symptoms remaining unresolved and continuing to reoccur. In the figure, the variables or processes associated with the symptoms and solutions are in sentence case.

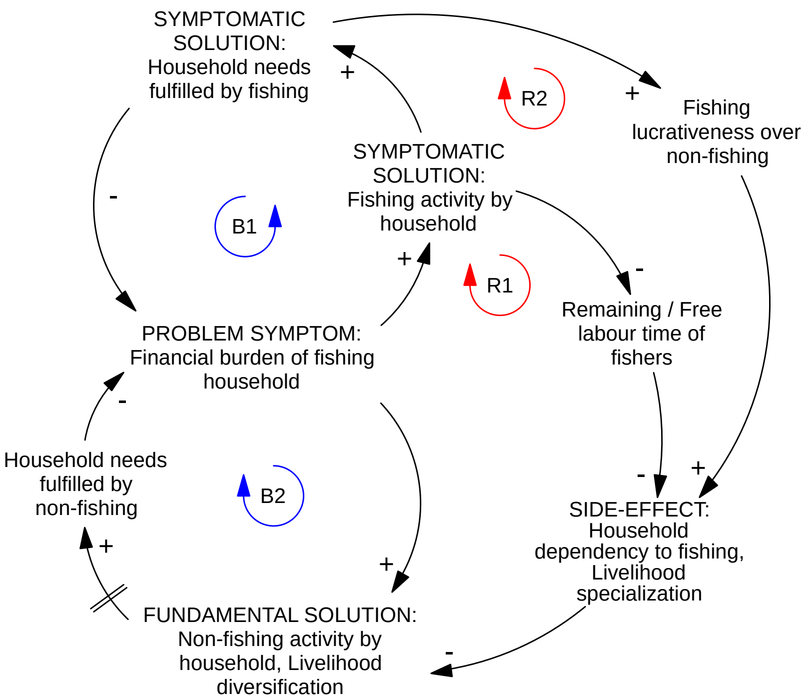

Figure 5-49. The identified "shifting the burden" archetypal structure.

The dynamics of the "shifting the burden" archetype were also illustrated by the dominant trends perceived by the problem-mapping FGD participants. As shown in Box A in Figure 5-50, in order to cope with increasing problem symptom of maintaining household economic needs (see red trend line), communities have been largely reliant (Figure 5-49) on the capture fishing (solid black trend line) activity to source their income needs (dashed trend line). However, since the existing capture fishing activity is collectively generating social and ecological undesirable consequences (e.g., the ‘trap from the fixes that fail archetype, Section 5.6.4.1), problem symptom such as economic needs/burden was maintained or re-emerged (red line). Thus, there was and will continue to be an increasing need for the implementation of a fundamental solution, such as household income-generating activity that is not dependent on fish extraction (dash-dot trend line). The dynamics stemming from the shifting the burden archetype were also illustrated by the dominant trends perceived by the problem-mapping FGD participants. As shown in Box A in Figure 5-50, in order to cope with increasing problem symptom of maintaining household economic needs (see red trend line), communities have been largely reliant (Figure 5-49) on the capture fishing (solid black trend line) activity to source their income needs (dashed trend line). However, since the existing capture fishing activity is collectively generating social and ecological undesirable consequences (e.g., the ‘trap from the fixes that fail archetype, Section 5.6.4.1), problem symptoms, such as the economic needs/burden were maintained or re-emerged (red line). Thus, there was and will continue to be an increasing need for the implementation of a fundamental solution such as household income-generating activity that is not dependent on fish extraction (dash-dot trend line). This dynamic is probably responsible for the perceived past trends. The rate of development and/or the economic output might, however, remain smaller in scale than fishing (see ‘non-primary livelihood activities’, Table 4-2) especially if livelihood diversification is not enhanced (see green variables in CLD 2.5, Figure 5-29). Box B in Figure 5-50 describes how the undesirable trends of the problem symptoms and of the side-effects of symptomatic solutions (red trend line), and desirable trends of the symptomatic and fundamental solutions (blue trend line) are influenced by feedback loops in the aforementioned shifting the burden CLD.

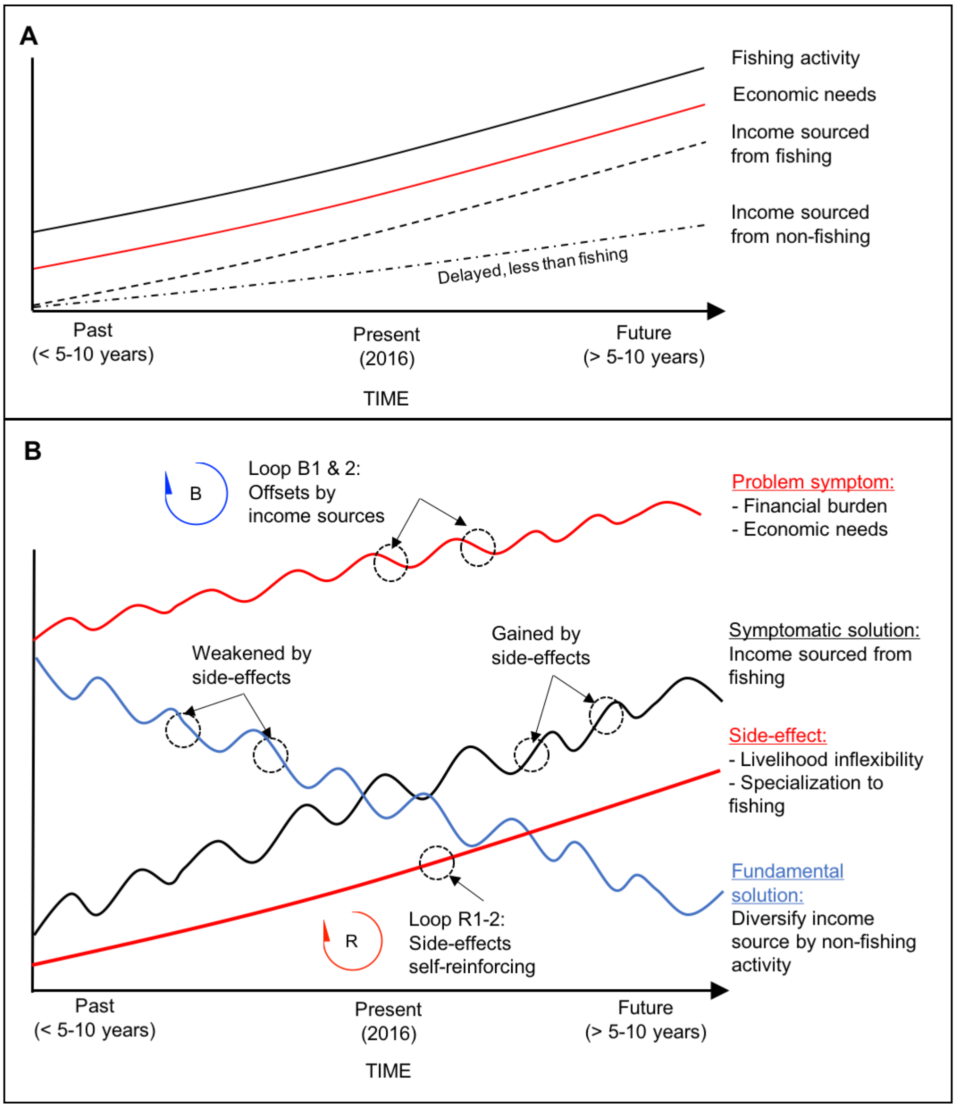

Figure 5-50. BOTG associated with the "shifting the burden" archetype.

The shifting the burden archetype relates to SET as it partly underlies the process that contributes to livelihood rigidity or inflexibility (as opposed to flexibility), whereby the choices or decisions made by the problem owner might have encouraged more effort towards the specialisation of a particular coping strategy such as fishing. Hence, a 'rigidity trap' (Carpenter & Brock 2008) might have occurred, which reflects the inability of the problem owners to change through improving their competency in a different livelihood strategy (i.e., loop influencing non-fishing work output, Section 5.6.3.8). The problem owner's unwillingness might be another cause for this inflexibility. In this regard, a 'gilded trap' (Steneck et al. 2011) might eventuate whereby fishing is perceived as the only economically viable economic strategy for the problem owner, who ignores the acknowledged undesirable social and/or ecological side-effects or consequences.

As identified in Section 5.6.4.1, efforts to work on the fundamental solution, such as to diversify livelihood, have taken place. However, it might not be at the level that allows the problem owner to independently alleviate their attachment to the symptomatic solution. As depicted in the final causal model, livelihood inflexibility of the fishers or households was also influenced by the changes occurring beyond the household scale and which may involve multi-actor/stakeholder decisions. In this case, collaborative solutions between the problem owners (e.g., resource users) and other stakeholders (e.g., government, civil society) (Campbell et al. 2005) are likely to be most effective.

5.6.4.3 Archetype 3: Limits to growth

As depicted in Figure 5-51, the limits to growth (also known as 'limits to success') archetypal structure begin with efforts (or actions) that create performances (or successes, growth) (see loop R1, R2). However, performances are being maintained temporarily (or only occurring in the beginning) since it is also linked to limiting factors (see loop B1, B2, B3). Over time, as the performances increase, so do the forces that constrain the performance. At some point in time, the balancing forces dominate, which causes the desirable performance or growth to diminish or to cease.

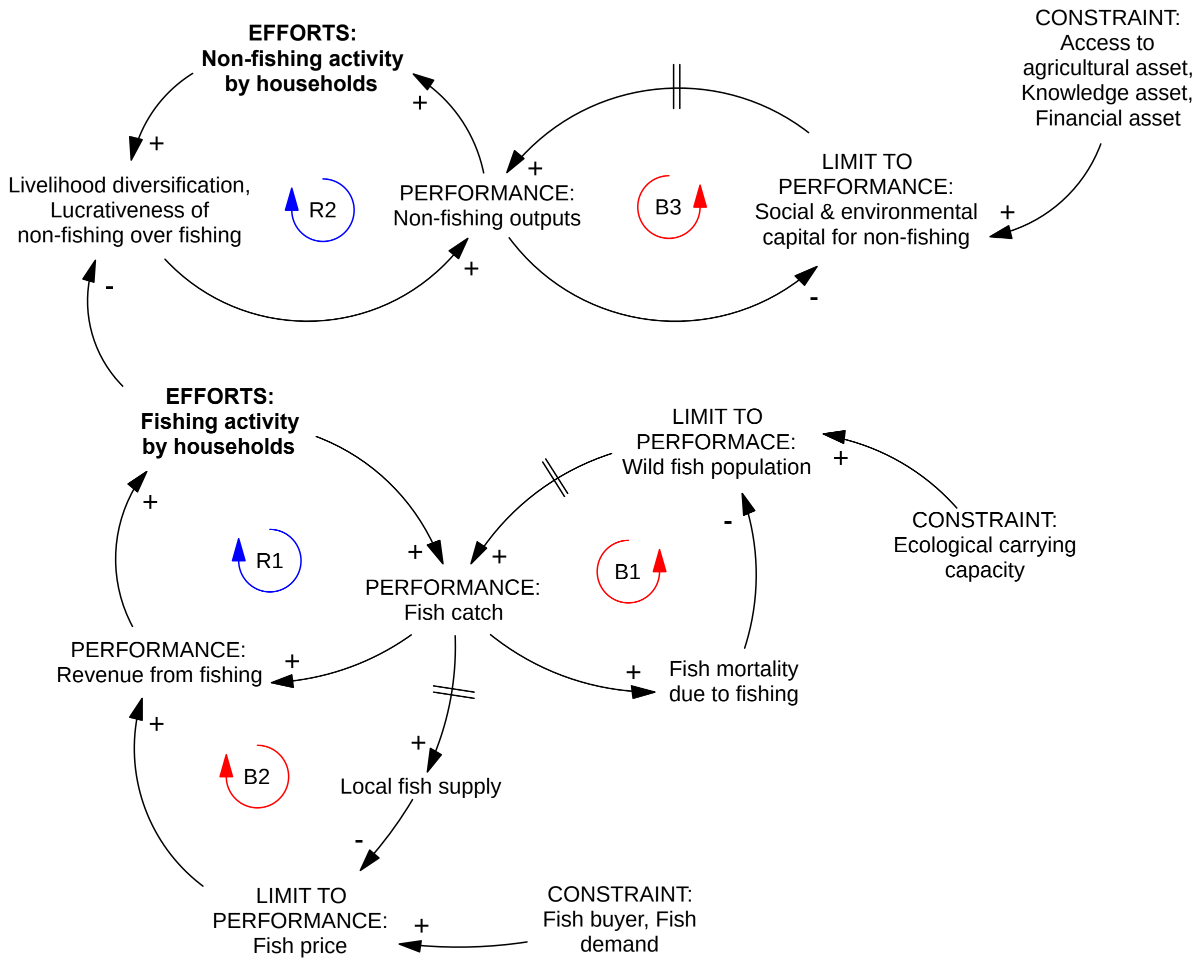

Figure 5-51. The identified "limits to growth" archetypal structure.

As illustrated in the BOTGs in Box A in Figure 5-52, the perceived trends of the effort in supplementary fishing and non-fishing occupations increased, and problem owners expected that trend to continue in future. However, parallel to this trend, the perceived past trend of the 'fish catch' performance had been and would continue declining. Given the strong indication of intensification of capture fishing and fish habitat damage in the past (see Section 5.6.3), the ecological capacity to supply wild fish in the local fishing grounds might have been reduced so that it slows 'fishing input' growth phase that may already slow. In this case, a driver of growth in the fishery might have become a driver in decline. At this stage, as illustrated by the BOTG in Box B Figure 5-52, the reinforcing feedback from past or future effort in fishing might no longer dominate (blue trend line). On the other hand, the balancing feedback from the ecological constraint might have already dominated in the past and would further contribute to the declining performance of the 'fish catch' in the future. However, at the time of writing, there is no data available that could help in delineating the ecological threshold conditions and which may explain whether the declining trend was/would be part of a transient change where the natural resource will still stabilise in harvestable state, or part of a trajectory of an ongoing wild fish depletion or collapse (see red trend line).

In the perspective of 'fishing output' performance, referring to the BOTGs in Box A in Figure 5-52, both the price of fish and the overall income from fishing were perceived as likely to increase. The trend is plausible as fish price partly reflects the increasing demand for fish (FAO 2016). However, the performance of fishing income (e.g., revenue from fish sales) might have, and may continue to be, constrained by the market since fish prices that are predominantly dictated by a limited number of buyer (due to oligopsonistic trade, see Section 5.6.3.3) or the patron (due to informal trading arrangement, e.g., Miñarro et al. (2016); Nurdin and Grydehøj (2014)). As a result, the suppression levels off the performance at a particular threshold (see the BOTG in Box B Figure 5-52, since additional reinforcement of revenue performance over the time would also be partly balanced out by the price reduction.

Therefore, despite a desirable increasing trend in price and income, fishing performance presumably was and would normatively be unchanging or even declining. This may occur in particular when the price suppression is no longer maintaining an income stream or profit level that can always support fisher/household to independently relieve their financial burden/obligations (see dependence to loan and debt, Section 5.6.3.7). Similar reasoning also applies to the performance of 'non-fishing outputs'. As shown in the BOTGs in Box A in Figure 5-52, the non-fishing/alternative livelihood effort was increasing, and it is expected that it will continue to increase. Yet, at some point in time, the reinforcement from the economic output of supplementary non-fishing work may level off due to the balancing feedback from the social, economic, and/or environmental livelihood asset constraints (red trend line intersecting with grey line, Box B, Figure 5-52, barriers to non-fishing/alternative livelihood improvement: Section 5.6.3.8). As a result, any additional performance, such as allocating labour effort for non-fishing work (see blue trend line, Box B, Figure 5-52) may not generate further economic output.

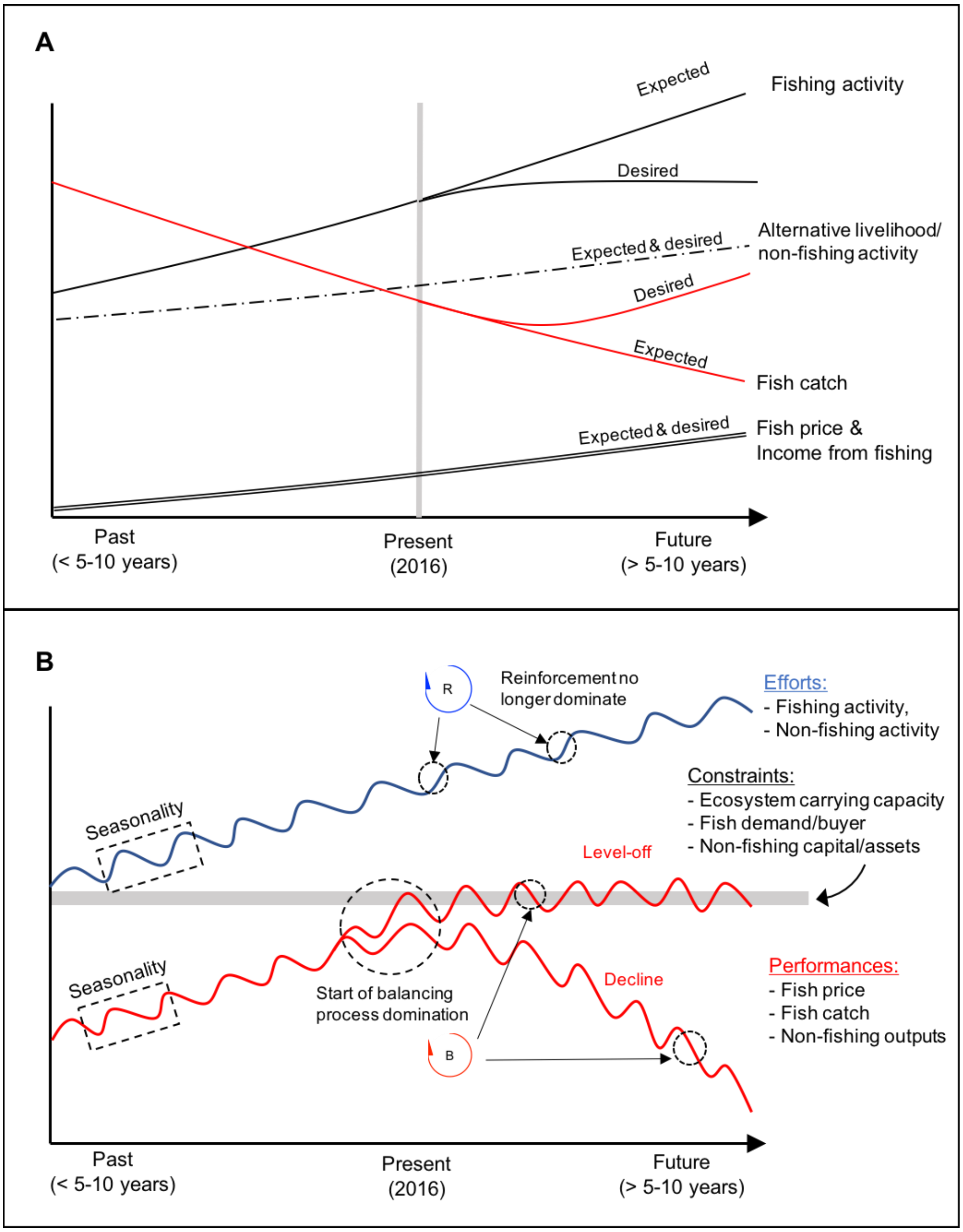

Figure 5-52. BOTG associated with the “limits to growth” archetype.

Given that delays are involved in the balancing process that ultimately slows down livelihood growth, performance, or success, the ‘limits to growth’ archetype has implications with reference to the BOTG in Box B Figure 5-52 to the maintenance SET - particularly when the problem owners fail to notice or heed the balancing process. The acceleration of fishing, which was initially a socio-economic coping strategy, may become a maladaptive strategy for the fishing community as the supply of fish on which they depend is constrained. Furthermore, although the problem owner is aware of the constraining factors to growth, the limits are predominantly influenced by exogenous factors (such as the fish price, fish demand, and social and natural capital/asset) which makes identifying the timing of the threshold when the limit is approached or crossed a difficult or impossible task for them. These external controls also create a dilemma for the problem owner since it also inhibits the internal effort necessary to [curtail] the SET situation (e.g., by diversifying into a non-fishing-dependent livelihood).

Most of these social and ecological limits cannot be eliminated but can be avoided by the problem owner through anticipation and management. Efforts towards understanding how the system is affected by limits to growth through identifying limits, how they may emerge, and the risks to the state of a complex system are possible through a multi-stakeholder learning process (Bennett, Cumming & Peterson 2005). In this regard, this understanding can help the problem owners and related stakeholders avoid making decisions that push the system harder, particularly when a limit is already eroding the desired system (Mai & Smith 2015).

5.6.4.4 Archetype 4: Tragedy of the commons

As depicted by reinforcing loops R3 and R4 in Figure 5-53, the ‘tragedy of the commons’ archetype situation includes the activity (fishing effort) of several actors in the system (fishing groups) to collectively utilise a common resource (local fish population). The common resource subsequently reinforced the amount of resources that can be gained by each actor (fish catch per unit of effort) and determines the maintenance of the collective activity while the resource is still available (see loop R3 and R4). Other than resource availability, as depicted in reinforcing loops R1 and R2, each actual resource gained by each actor (in terms of fish caught by each fishing group) also motivates actors to continue or increase the activity. However, fishing groups tend to focus on their own benefit or objectives as many fish resources considered here are viewed as ‘owner-less’, unmanaged, and/or open and freely available to all. Since the common resource availability has an ecological limit that determines resource renewal (i.e., the regeneration rate of the fish population), at some point the total activity (fishing effort of all groups) will ‘overload’ the commons (i.e., fish being harvested faster than they can recuperate). When the resource supply is exhausted or collapsed, the potential resource that can be gained for the same unit of activity starts to decline and the actual resource that can be harvested by each actor is less than before or may even no longer exist (see balancing loops B1 and B2).

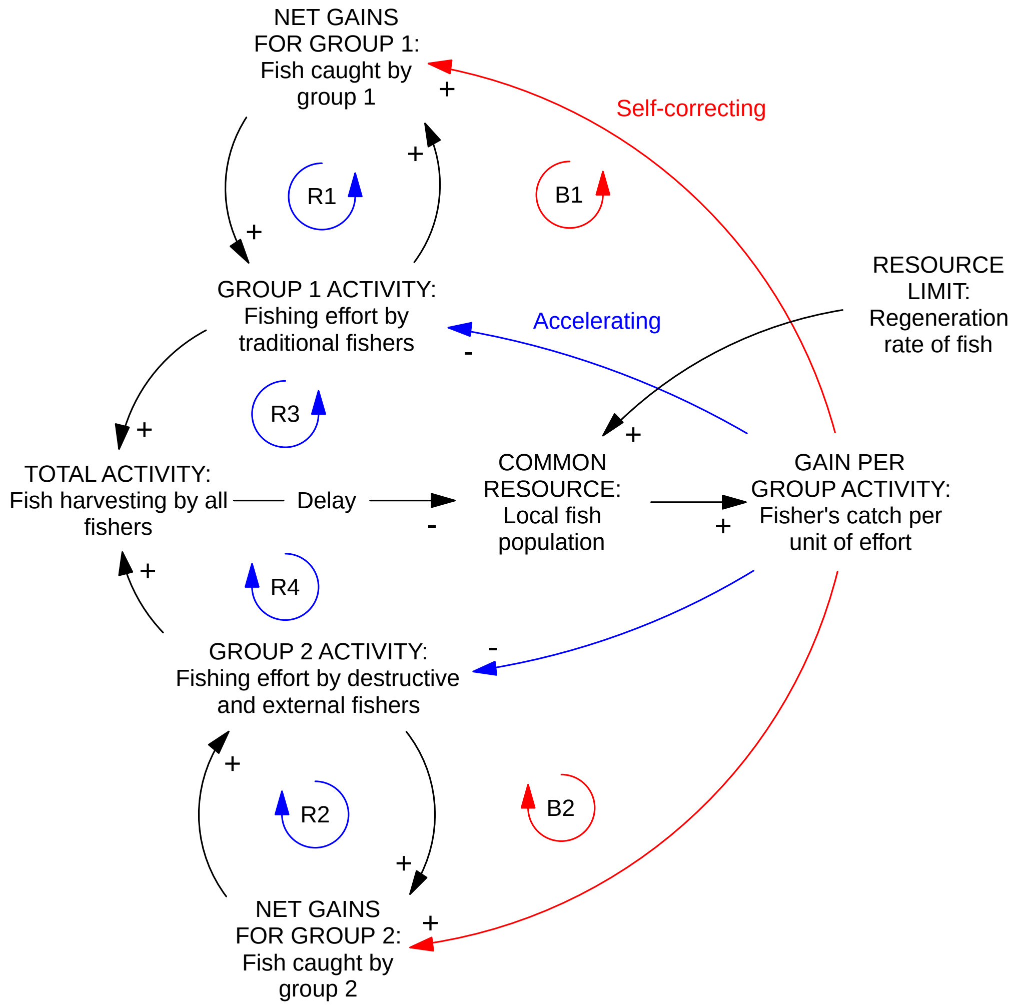

Figure 5-53. The identified “tragedy of the commons” archetypal structure.

A number of trends perceived by the FGD participants support the hypothesised dynamics of the ‘tragedy of the commons’ archetype. Referring to the BOTG in Box A in Figure 5-54, the total fishing activity (mainly performed by the traditional fishers, the external fishers, and the traditional-but-destructive fishers) has increased and that trend was expected to continue, although most of the desired future trend of fishing activity was to adopt a slower rate or even at a constant level. In relation to the archetype, the perceived effort trend may represent the initial phase that involves gradual increase or the second phase that involves accelerated increase of total activity (see blue trend line, in Box B in Figure 5-54). Total activity is being maintained by the reinforcing loops (loop R1, R2, R3, R4). Parallel to this, also referring to the BOTG in Box A in Figure 5-54, the perceived trend of fish resource, fish catch, and the ease of catch had been decreasing, and this was a trend that was likely to continue. Yet the desired future trend was the opposite. In relation to the archetype, this perceived declining trend of the common resource and the gains made by the fishing groups may represent one of the phases of decline (see black and red trend lines, in Box B in Figure 5-54), which is being maintained by the balancing loops (loop B1, B2).

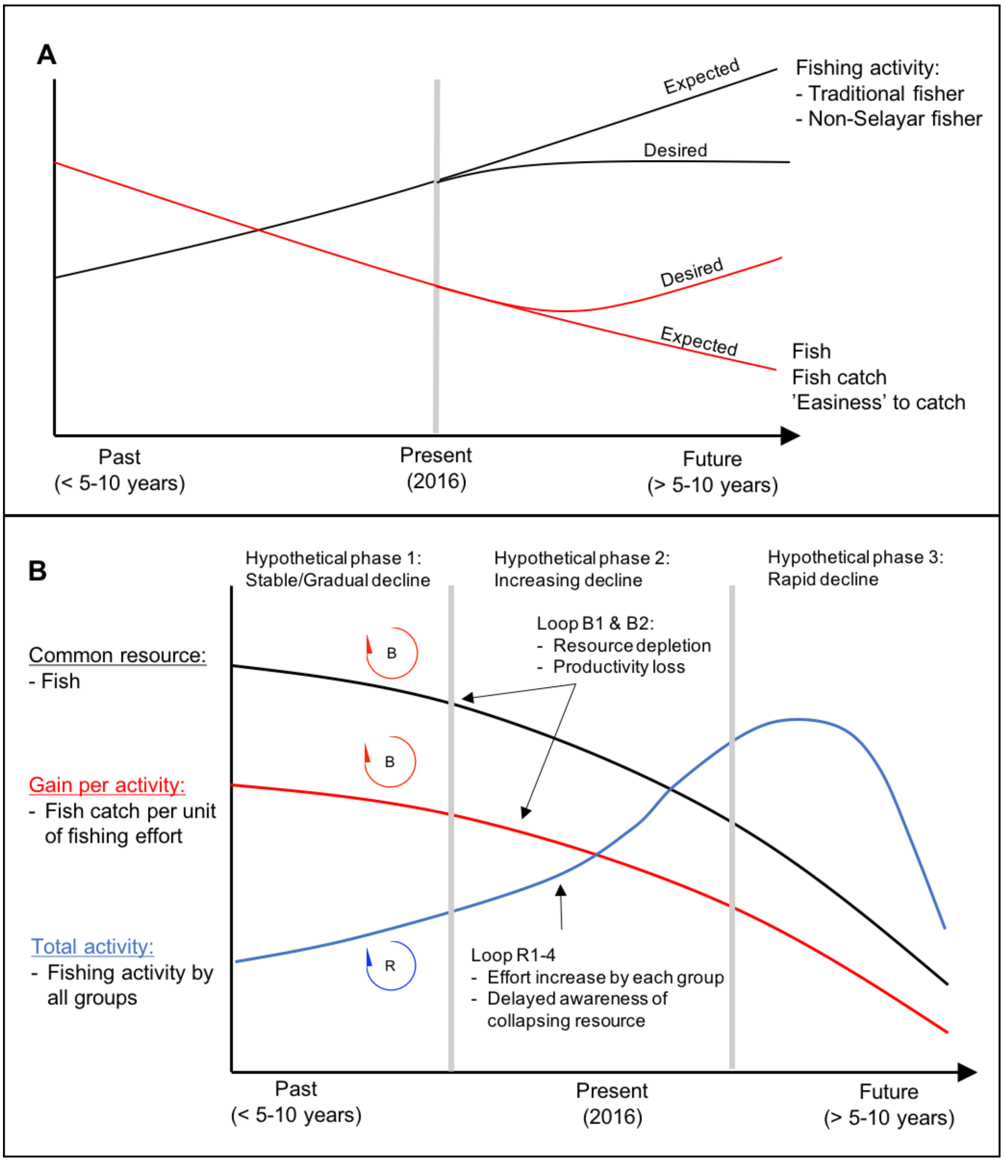

Figure 5-54. BOTG in the "tragedy of the commons" archetype.

Given that avoiding the 'tragedy of the commons' is desirable, problem owners might translate recent changes (declining fish and productivity loss) as a signal that there are limits and act to reduce exploitation. This said, there is little information available for helping problem owners estimate and hence avoid the threshold for 'commons' resources to collapse. At the same time, there is presumably a lack of incentive for fishing groups to change their individual efforts. Therefore, the total resource use activity might already in an accelerated increase (hypothetical phase 2, Box B in Figure 5-54). In this assumption, without intervention or corrective actions, a SET can ensue since the growth of activity is likely to be heavily influenced by the scarcity of the resource. This might have been depicted by the identified expectations or decision during FGD where fishers would be better-off using more effective but potentially damaging fishing gear, or larger boats and gear with a higher catch capacity. Thus, the trajectory towards hypothetical phase 3 (as seen in Box B) is probable and would trap problem owners in an unproductive livelihood activity that is attached to a depleted resource.

The tragedy of the commons problem has long been recognised in the fisheries literature (e.g., Berkes (1985); Feeny, Hanna and McEvoy (1996); McWhinnie (2009)). To manage the problem, authors have suggested that interventions should be focused on overcoming social conflict among resource stakeholders to encourage a collective effort that will ultimately slow down or stop resource overexploitation (Basurto 2005; Vollan & Ostrom 2010; Wilkinson & Salvat 2012). However, this can become a challenging task since fish resource depletion, social conflict, and competition among resource users may be mutually reinforcing, and each of these conditions may be exacerbated by a different array of factors (Pomeroy et al. 2016). The tragedy of the commons in Selayar, therefore, already presents a social-ecological systems problem of its own and may require a collaborative problem management approach, as discussed in Section 2.3.2.

5.6.4.5 Synergies of reinforcing loops that maintain undesirable path-dependencies

In a broader perspective, from the resemblance of the outcomes of the identified archetypal situations, a path-dependence archetype was able to be distinguished, which can also rationalise the path-dependence process discussed in Sections 2.1.3 and 2.2.4. As shown in the CLD in Figure 5-55, the archetype consists of two reinforcing loops (R1, R6) linked by a common variable. At a macro-level perspective, the two loops depict the system’s self-reinforcing cycles that determine whether the system outcome would be an undesirable (by loop R1) or a desirable (by loop R6) livelihood system state. Yet, in the context of a problem, the structure ensures that an undesirable livelihood state persists due to the over-dominating reinforcement of maladaptive response (loop R1) by the problem owner.

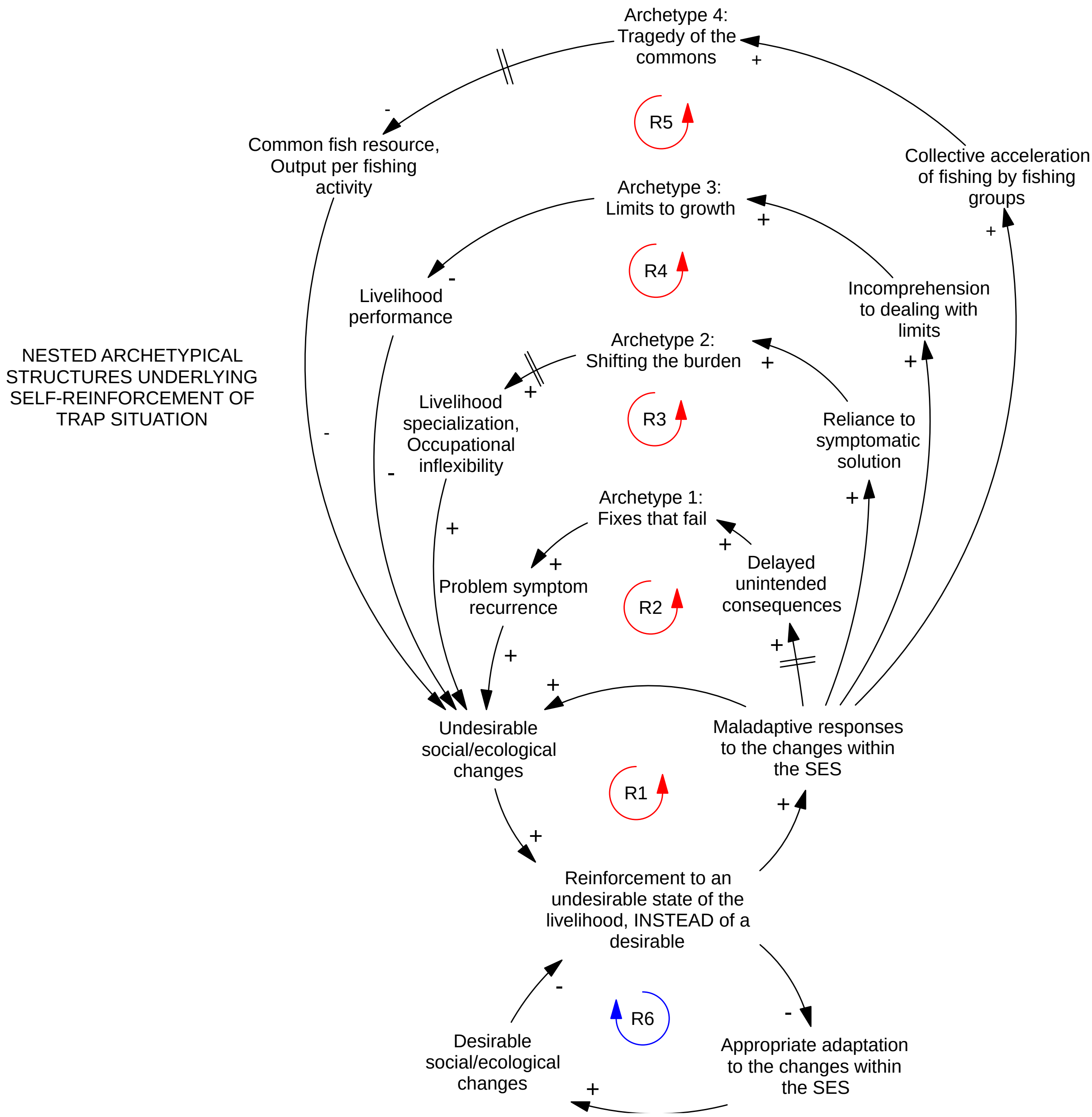

Figure 5-55. The identified "path-dependence" archetypal structure.

At a small-scale perspective, the continuation maladaptive coping can be attributed to the fundamental decision-making problems reinforced in the earlier four archetypes (see reinforcing loops R2, R3, R4, and R5 in Figure 5-55). The problems include the inability to comprehend delayed unintended solutions (fixes that fail), the reliance to symptomatic solutions (shifting the burden), the incomprehension to dealing with limits (limits to growth), and the collective acceleration of resource use (tragedy of the commons). Subsequently, the feedback mechanisms within each of the archetype reproduced the antecedent conditions that are responsible to undesirable socio-ecological outcomes, which are mainly the depletion of natural resource (tragedy of the commons), reduction of livelihood economic output (limits to growth), specialisation of a particular livelihood activity (shifting the burden), and recurrence of livelihood economic problems (fixes that fail). Ultimately, this 'legacy' of undesirable changes would be responded to with another maladaptive measure (loop R1).

As depicted by the solid red trend line in the BOTG in Figure 5-56, the domination of reinforcement to past episodes of maladaptation might have maintained a path of change that perpetually pushed the livelihood system towards an undesirable configuration of social and ecological states or 'deeper into the trap'. However, at this stage of analysis, there is a high degree of uncertainty as to whether the perceived undesirable trends are still within the 'critical juncture' phase. In this phase, it is expected that the system instability still allows appropriate adaptation to take place, for example, by means of reconfiguring the behaviour of actors to maintain a different livelihood arrangement but socio-ecologically more desirable. Or, the identified trends might be part of an unstable livelihood state that is already in a lock-in phase. In this phase, it is assumed that most of the ecological thresholds (i.e., for the fish resources to decline) and/or social thresholds (i.e., for the fishing community to become resistant to policies) have already been crossed, which makes proper adaptation too difficult or impossible to initiate.

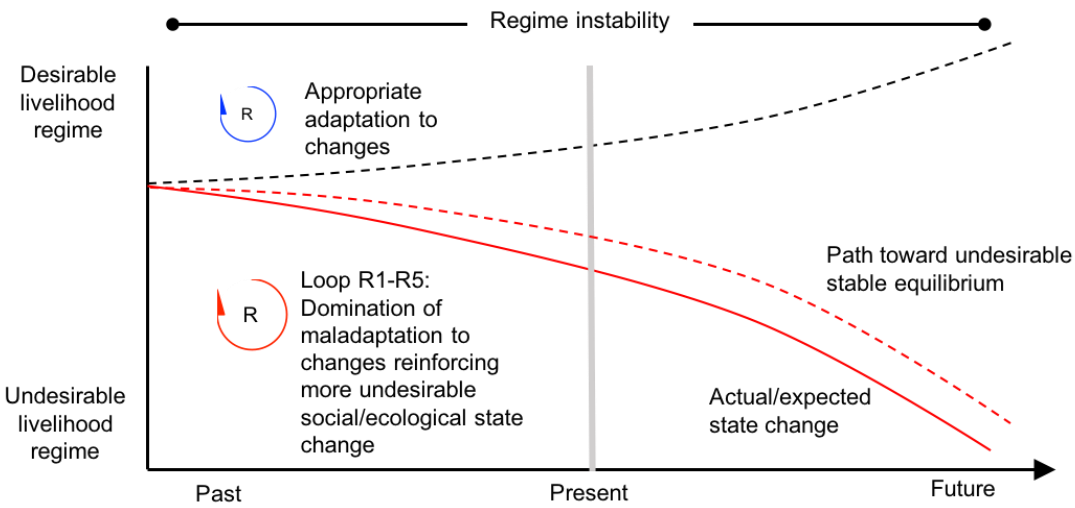

Figure 5-56. BOTG associated with the "path-dependence" archetype.

The path-dependence archetype identified here signifies that the SET inherent to the 'declining reef fisheries' problem is difficult to solve or avoid, due to the nested self-reinforcing feedbacks. As demonstrated in the previous archetypes, these feedback mechanisms involve cross-scale interactions that span different temporal and spatial scales (i.e., some influences are from the past, have a delayed effect, and/or are outside the problem owner's spatial influence) and between different individuals, organisation or institutions (e.g., problem stakeholders, Section 4.1.2.3), from different levels (e.g., household, community, beyond the island). To compensate and weaken the episodes of problematic feedbacks, the management process may warrant a 'cyclical' and multi-stakeholder problem-solving process such the adaptive co-management (ACM) (Whitney et al. 2017). Although this stage of analysis is far from providing a practical solution, the complexity and interconnectedness captured in this chapter itself an informational solution in operationalising ACM (Scarlett 2013).

5.6.5 Summary: Implications of the causal modelling results to the grounded concepts and theories

In relation to the exploratory framework of this research (Section 2.4.1), the identified boundary of the examined livelihood system (Section 5.6.1) and the final causal model (i.e., CLD 3: Figure 5-32 and Figure 5-33) illustrate the hypothesised complexity of the SES responsible for the *declining reef fisheries* problem (e.g., the structure of the system and interactions among variables: blue box, Figure 2-10; Section 2.2.2). Feedback structures (i.e., blue box, Figure 2-10; Section 2.2.2) were also prominent (i.e., Sections 5.6.3, 5.6.4), formed by the interdependencies between endogenous and exogenously influencing variables (i.e., Section 5.6.2, 5.6.3). The identified feedback loops (i.e., Section 5.6.3) and the archetypical structures (i.e., Section 5.6.4) conceptually justify the theoretical non-linear dynamics of multiple state variables produced by the feedback mechanism (i.e., bottom green box, Figure 2-10, Section 5.6.2). These dynamics (depicted by the BOTGs) conclusively demonstrate the adaptive capacity of the SES as illustrated by the portrayal of the *latitude* property (brown box, Figure 2-10; Section 2.2.3). This was also depicted by the different system states (e.g., changing levels of the state variables) that might have been experienced in the past, and may possibly occur in the foreseeable future. *Resistance*, the second attribute of SES resilience (brown box, Figure 2-10; Section 2.2.3), was able to be gauged by the failing efforts of the system actors when coping within a problematic livelihood ‘regime’ (i.e., Figure 5-56). This was also emphasised by their maladaptive responses to the undesirable livelihood state changes (i.e., Figure 5-55). *Precariousness*, the third resilience property (brown box, Figure 2-10; Section 2.2.3), was also reflected by persistence of the system in a problematic trajectory of change (i.e., path-dependence archetype, Section 5.6.4.5) although it is unclear whether a pre-lock-in or lock-in phases were already being exhibited at the time of the study (Section 5.6.4.5). Furthermore, the nested self-reinforcing feedbacks that were identified (i.e., Section 5.6.4.5) originate and occur at different spatial (e.g., household, community, individual, species interactions) and temporal scales (e.g., slow feedbacks: fish recuperation, fast feedbacks: fish extractions, household decisions). In the context of the problem of interest, this signifies complexity at multiple-scales as has also been identified for other marine and coastal systems (Glaser & Glaeser 2014; Leslie et al. 2015)}.

The sustainability problem of the local small-scale fishery in Selayar also exhibits the prevalent linkage between livelihood insecurity (e.g., household debt trap), market-related pressure (e.g., fish oversupply) and rapid exploitation of natural resources that are also found on a global scale (e.g., Berkes et al. (2006); Eriksson et al. (2015)). Overall, the causal model analysis asserts that the aim of maintaining the sustainable outcome small-scale fishing livelihood and the associated natural resource system in Selayar will remain a significant challenge if the system remains in a state of 'low' resilience (i.e., caught in the social-ecological trap that has been identified, Section 5.6.4.5) and under a potentially irreversible undesirable livelihood state (i.e., due to the maladaptive internal capacity, Section 5.6.4.5). This outcomes has characteristics that are similar to those found in other systems, mainly of rapid biodiversity loss and decreasing livelihood opportunities (e.g., Boris Worm et al. (2006); Millennium Ecosystem Assessment (2005b). The associated path-dependence archetype (Section 5.6.4.5) implies that achieving sustainable small-scale fishing livelihoods in Selayar will involve appropriate adaptation measures that reinforce desirable social and ecological changes. Although some response measures were suggested by the problem stakeholders (i.e., Decisions variables related to diversification of livelihood, and surveillance and enforcement, Figure 5-9, Figure 5-10), the performance of these measures might may have been insufficient to compensate for the synergies of reinforcing feedback that maintain the undesirable livelihood regime. This situation might have been partly caused by the unpredictable and non-linear changes of key internal system variables or external drivers (from human behaviour [e.g., the external fishers and destructive fishing groups]: Anderies, J. M. (2015), in ecosystem behaviour [e.g., fish population, weather disturbances to fishing]: Scheffer, M. et al. (2001)) that were not considered in these decisions. Therefore, this might have led to livelihood or problem-response decisions that were fixed on optimisation objectives such as maximising output for a short time frame or which narrowly focused on individual events (Fischer et al. 2009; Holling & Meffe 1996; Johnson, Williams & Nichols 2013; Peterson, Carpenter & Brock 2003).It is also acknowledged, however, that there is a high degree of uncertainty regarding the timing, magnitude, and variability within the hypothesised problematic non-linear changes (i.e., bottom green box, Figure 2-10, Section 5.6.2) that this assessment cannot explicitly measure. Hence, the CLDs and BOTGs were treated as a point of reference for developing a computer-based model to simulate the problem and explore the solutions as well as adverse consequences of particular decisions in Activity 5 (Dynamic modelling; Methodology: Section 3.6.5; Results & discussion: Chapter 6),. Furthermore, I explore several policies in Chapter 7 based on the identified Decisions variables that have the potential to modify the behaviour of the state variables and which test the effectiveness of these policies using the simulation model to screen the most promising entry points to solve specific livelihood problems.

Causal modelling promotes an understanding of how complexity influences the sustainability of an SES (Leslie et al. 2015). Additionally, the participatory knowledge generation about a data-poor system (i.e., problem mapping in Selayar) also demonstrates how local ecological knowledge as well as traditional knowledge is critical for understanding livelihood sustainability (Glaser, Christie, et al. 2012). This approach has enabled the problem stakeholders (e.g., the researchers and/or the participating communities) to understand parts of this underlying complexity by exploring other domains of the system and thus, minimising incomplete information when a problematic system is explored using the tools of a single discipline (e.g., in social: Parsons (2005), economic: Wooldridge (2012), ecological: Jørgensen (2009), and social-ecological: Ostrom, E. (2009) system). Finally, the findings of this assessment have answered Questions 2 and 3 of Main Assessment 1 (Section 2.4) by qualitatively exploring the system components and their interactions, as they relate to the topic problem at the heart of this thesis. The assessment has also conceptually addressed Question 1 of Main Assessment 3 (Section 2.4) by diagnosing the feedback processes as one of the surrogates of resilience.

Chapter 6 Dynamic modelling of the socio-ecological system

This chapter discusses results derived mainly from the dynamic modelling (Section 3.6.5) partially from secondary information collation (Section 3.6.6).

6.1 Result 1: Stock-and-flow model of the system

6.1.1 The diagram of influence of the base case model

As shown in Figure 6-1, an influence diagram was developed derived from the state variables, variables, and relationships conceptualised in CLD 3 (Figure 5-30, Figure 5-31). The influence diagram was used as a starting point for developing stock-and-flow diagrams (SFD) in the Stella® Architect software, which is explained in the next section. The state variables, variables, and relationships conceptualised in CLD 3 were represented by one or several elements in the SFD sectors as listed in Table 6-1 and Table 6-2.

Table 6-1. List of the state variables in CLD 3 that are represented by the SFD sectors.

Variable no.	State variable name	Sector no.	Sector name
1	Coral reef and other fish habitat condition	1	Seagrass and mangrove fish habitat condition
		2	Coral reef fish habitat condition
2	Local fish population	3	Fish population
3	Fish catch	5	Fish catch
4	Destructive fishing effort	2	Coral reef fish habitat condition
		4	Fishing boat
		9	Effort for fishing
		17	Fishery groups
		18	Adjusted inter-fishery movement and fisher entries and exits
5	Local fishing activity	9	Effort for fishing
		4	Fishing boat
		17	Fishery groups
		18	Adjusted inter-fishery movement and fisher entries and exits
6	Fishing activity of households	16	Human population
		4	Fishing boat
		9	Effort for fishing
		17	Fishery groups
		18	Adjusted inter-fishery movement and fisher entries and exits
7	Immigration and human population	16	Human population
8	Fish price	7	Fish demand and fish price
9	Total costs of living (Financial burden)	12	Household costs of living
9	Total costs of living (Financial burden)	13	Household net income (savings)
10	Total household income	13	Household net income (savings)
11	Costs of living fulfilment (State of living)	13	Household net income (savings)

Variable no.	State variable name	Sector no.	Sector name
12	Household savings / net income	13	Household net income (savings)
13	Debt/loan taking	20	Household loan and debt

Table 6-2. List of variables and relationships in CLD 3 that are represented by the SFD sectors.

No.	Variables / Relationships	Sector no.	Sector name
1	Fish from destructive fishing	5	Fish catch
2	The ratio of domestic fish supply to demand		
2	The ratio of domestic fish supply to demand	7	Fish demand and fish price
		6	Fish supply
3	Labour hours available for non-fishing work	10	Effort for non-fishing (by fishers)
		11	Effort for non-fishing (by non-fishers)
4	Labour support within and outside the household		
5	Fish demand for destructive fishery	6	Fish supply
		7	Fish demand and fish price
6	Household fishing outputs	8	Profit of fishing
7	Fishing costs		
8	Regional costs of living	12	Household costs of living
9	Desired costs of living		
10	Household needs to be fulfilled by fishing	13	Household net income (savings)
11	Household needs to be fulfilled by non-fishing		
12	Reinforcing feedback between: Household savings / net income, and: Desired costs of living	14	Household deficit level
13	Intermediary variable between the positive influence of: household savings and emigration of labour in the fishing households	15	Household tertiary education capacity
14	Community-based surveillance at local level, as part of: The social-political factors discouraging external fishing and destructive fishing	18	Adjusted inter-fishery movement and fisher entries and exits
15	Attractability of fishing over non-fishing	18	Adjusted inter-fishery movement and fisher entries and exits
16	Weather-related hazards	19	Determinants of fisher entries & exits and of fishing effort
17	Risks and uncertainty in fishing		
18	Weather unpredictability to local fishing activity		
19	Loan repayment	20	Household loan and debt
20	Non-fishing work effort	21	Profit of non-fishing (Bio-LEWIE based)
21	Non-fishing job costs		
22	Non-fishing outputs		

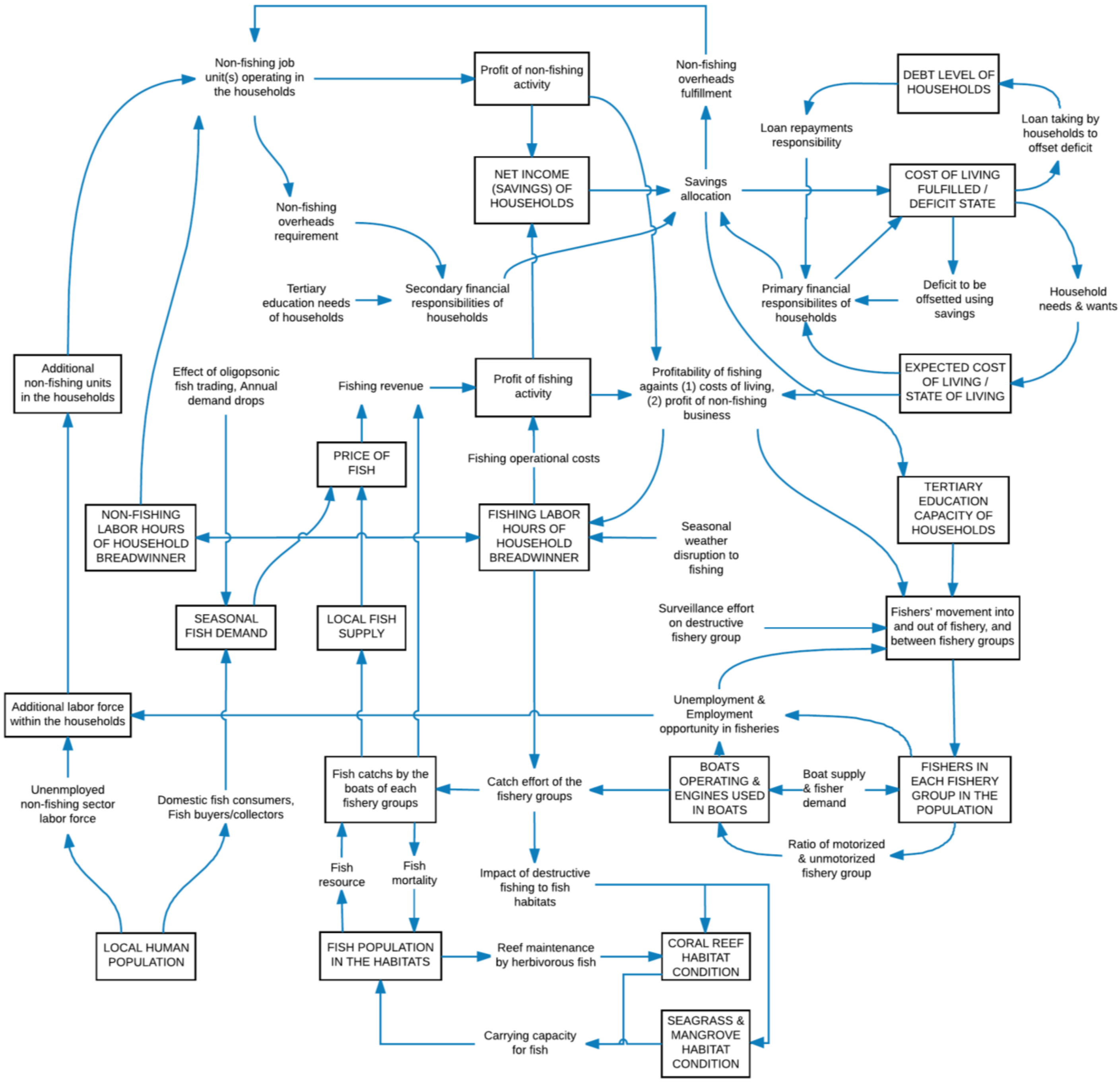

Figure 6-1. Diagram of influence. Arrows denote influence among the system components or processes but do not represent the material flow. Boxed text denotes variables represented as sectors containing functionally-related SFDs. Text in capitals indicates sectors representing state variables and thus include stocks

6.1.2 Stock-and-flow structure for the base case model

A large SFD was developed together with the team in the Stella® Architect software to model the 'base case' (see Section 3.6.5.2) condition of the Selayar Island small-scale fisheries system. The base case SFD was organised into 21 sectors of SFDs and had a total element of about 140 stocks, 660 flows (of inflows, outflows, and bi-flows), 520 constant value input converters, 810 equation converters, and 59 graphical input converters. This included variable 'duplicates' due to arrayed variables in the SFD (more in Section 6.1.3). The detailed base case SFD represented in the represented in the Stella® Architect software that can be found in Appendix 18.

To maintain the narrative flow of this chapter, I have only included the simplified version of the base case SFD which I have separated into five parts for readability and which can be found in Figure 6-2, Figure 6-3, Figure 6-4, Figure 6-5, and Figure 6-6; respectively. These parts are used in the next subsections to help explain the general design of each sector's model. To maintain the narrative flow, the structure of these subsections follows the sequence of the sectors presented in the parts of the simplified SFD.

In each subsection, I will refer to segments of the detailed SFD found in Appendix 18 where the reader can find the SFD variables and the embedded Stella® equations input values (in other appendices: Section 6.2.2) that underlie the simplified model.

6.1.2.1 Seagrass and mangrove fish habitat condition (Sector 1)

Sector 1 (SFD in Figure 6-2) models the carrying capacity (CC) for fish of the seagrass and mangrove habitats. The CCs are positively influenced by the changes in seagrass and mangrove habitat conditions (i.e., biomass and area). The seagrass condition is dynamically modelled, and the other stocks are defined as static ecological parameters. Seagrass is negatively influenced by the frequency and magnitude of seagrass loss due to cyanide fishing.

For the base case, in this sector and also in Sectors 2 and 3, the normal and current conditions of the ecological variables were largely 'proxy' estimates. This means the estimation mostly uses secondary information of in-situ and/or ex-situ observations or experiments from areas outside the Selayar region that can provide the best-available data resolution to reflect the spatial and temporal conditions required for the model parameter. The detailed SFD can be found in segment 1-A, 1-B, and 1-C in Appendix 18.

6.1.2.2 Coral reef fish habitat condition (Sector 2)

Sector 2 (SFD in Figure 6-2) models the carrying capacity (CC) for fish of the coral reef habitat, which is positively influenced by the changes in the reef condition. The reef condition is modelled as a function of the living substrate in the reef (LSR), reef rubble, and reef condition index (i.e., biomass and area). LSR is negatively influenced by the rate of substrate conversion to rubble, which is resulted from the impact of both blast and cyanide fishing. The detailed SFD can be found in segment 2-A, 2-B, 2-C, and 2-D in Appendix 18.

6.1.2.3 Fish population (Sector 3)

Sector 3 (SFD in Figure 6-2) models fish population using two stocks of size-based fish age groups of *juvenile* and *adult fish* for each of the fish habitat dimension elements. The *Juvenile fish* group is influenced by the inflow of fish recruitment and outflows as maturing fish to the *adult fish* stock group. The rate of recruitment is dependent on the proportion of productive female *adult fish.* The current CC for fish from each habitat positively influences the rate of fish recruitment and fish maturation. For the base case, the fish mortality rate due to fish harvesting by the fishing groups only affects adult fish stock assuming an 'ideal' situation where fishers would avoid catching 'baby' fish. The detailed SFD can be found in Figure 1-10 to Figure 1-15 in Appendix 18.

6.1.2.4 Fishing boat (Sector 4)

Sector 4 (SFD in Figure 6-2) models fishing boats using two stocks of *occupied* and *unoccupied fishing boats*. The occupied boats are also arrayed by boats with a motor (i.e., boat engine) and without a motor, represented by the *occupied motors* and *unoccupied motor* stocks, respectively. In the detailed model, the boat and motor are influenced by the outflows of decommissioned boat/motor (i.e., due to its lifespan), and the inflows of purchased boat/motor. The rate of occupation and abandonment of boat/motor are influenced by the change of the total fishers (for boat stock) and the proportion of fishers with motorised boats (for the motors). For the base case, new boat and boat motor purchases were not applied assuming that small-scale fishers tend to resort to reusing and refurbishing old or existing motors or boats, which makes the purchase rate very low. Thus, the initial number of boat motors was set to be equal to the initial number of motorised boats. The detailed SFD can be found in segment 4-A and 4-B in Appendix 18.

6.1.2.5 Fish catch (Sector 5)

Sector 5 (SFD in Figure 6-2) estimates the total mass of the fish from each fish class that are being caught by all fishing boats of each fishery group, in each fish habitat (i.e., fishing ground). Fish catch is modelled as a product of the number of boats operating, the hours of fishing activity, the average fish weight per individual adult fish, the normal catch per unit of effort (CPUE) of the boats, and the positive influence of fish density change to the current CPUE. The detailed SFD can be found in segments 5-A and 5-B in Appendix 18.

6.1.2.6 The effort for fishing (Sector 9)

Sector 9 (SFD in Figure 6-2) models the *fishing effort hours per boat* stock, which informs the average weekly total fishing hours allocated by each fisher (i.e., boat) in each fish habitat. Fishing effort is limited by the average maximum weekly labour hours of the fisher. The allocation of fishing effort in each habitat that is influenced negatively by (1) a weather hazard in reducing fishing effort; positively by (2) the profitability of fishing in fulfilling costs of living, and (3) in comparison to the profit of the household non-fishing livelihood activity. These influences are modelled in Sector 18 and 19 (Section 6.1.2.20). The detailed SFD for this sector can be found in segment 9-A, 9-B, and 9-C in Appendix 18.

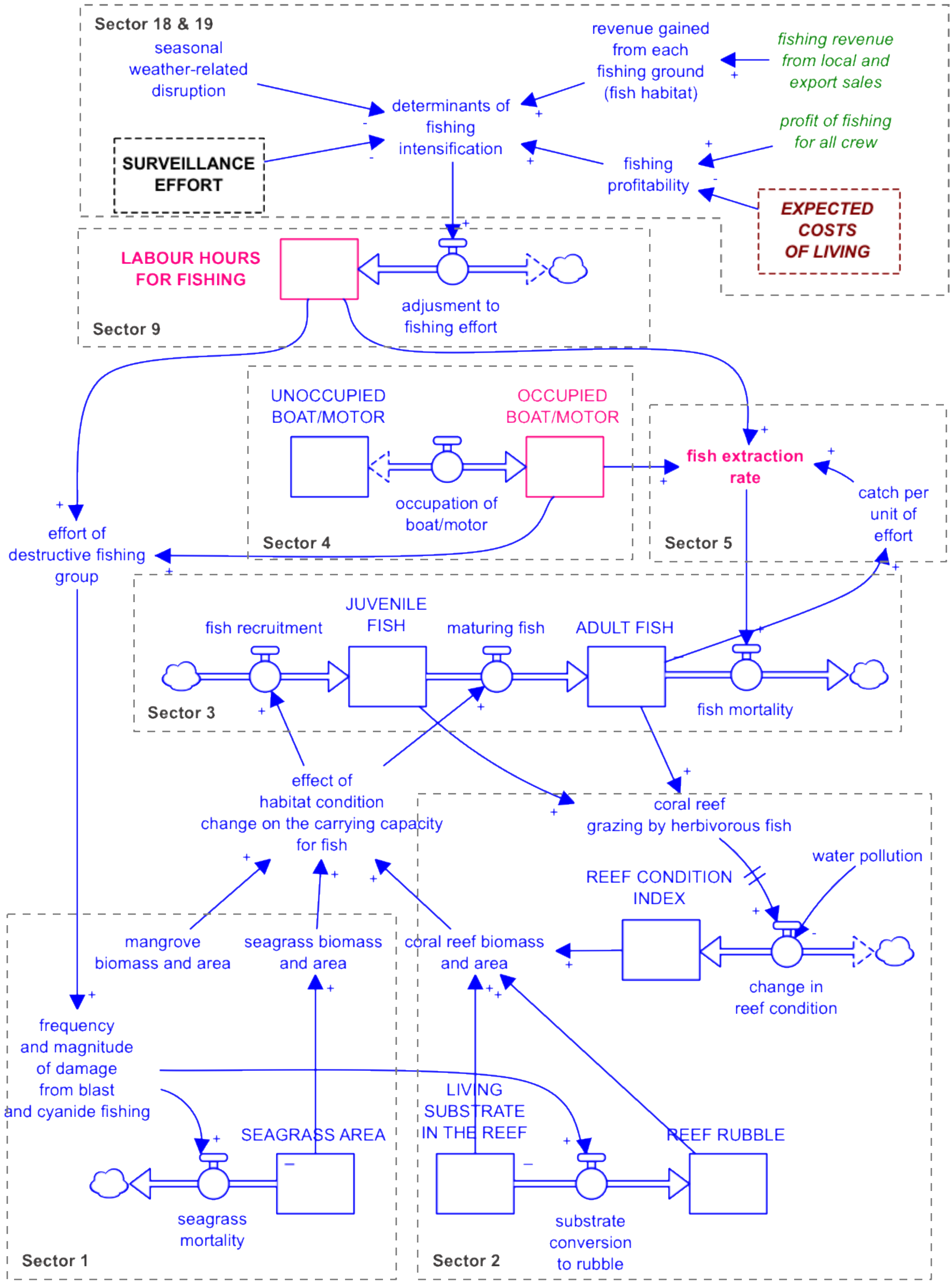

Figure 6-2. Part one of the base case model. Stocks/flows/variables from this part that are linked to another part (or parts) are displayed in red. Variables inside the dashed-lined box refer to stocks originating from other parts. The sector number refers to the same sector number contained in Table 6-1 or Table 6-2. The SFD inside dashed boundary lines represents the model of the indicated sector.

6.1.2.7 Fish supply (Sector 6)

Sector 6 (SFD in Figure 6-3) models fish supply using the *fish landed locally* stock that receives the inflow of local fish supply based on the fish caught by fishers (from Sector 5). The landed fish outflows to supply local fish trade (i.e., if there is local fish demand) and/or to the unsold fish stock. In the model, the fraction of fish catch supplied (i.e., sold) for local and for export demand are of a fixed value; yet, the rate of local fish demand is dynamically modelled in Sector 7. The detailed SFD for this sector can be found in Figure 1-20 in Appendix 18.

6.1.2.8 Fish demand and fish price (Sector 7)

Sector 7 (SFD in Figure 6-3) estimates the local fish demand based on the fish purchase by non-fishing households, which reflects the outflow of sold fish in Sector 6. The current ratio of local fish supply to demand negatively influences current *local fish price*, which is modelled using an information stock. As feedback, the change in the current local fish price relative to the normal price negatively influences local fish demand. The detailed SFD can be found in Figure 1-21 in Appendix 18.

6.1.2.9 Profit of fishing (Sector 8)

Sector 8 (SFD in Figure 6-3) estimates the weekly average of profit of fishing of the breadwinner fisher based on the total fish sales revenue, the total costs of fishing, and the share of profit for the fisher as a member of the crews of the fishing boat. The detailed SFD can be found in segment 8-A, 8-B, and 8-C in Appendix 18.

6.1.2.10 Household costs of living (Sector 12)

Sector 12 (SFD in Figure 6-4) models the change in the *expected costs of living* of households using an information stock, as a product of the normal costs of living (i.e., minimum provincial living standard) and the annual inflation rate. The expected costs of living are negatively influenced by the current unrecovered household deficit (from Sector 14), assuming that fisher/household would reduce their expectation when deficits occur recently. The stock is treated as one of the inputs for the prioritisation of household spending allocations in Sector 13. The detailed SFD can be found in Figure 1-31 in Appendix 18.

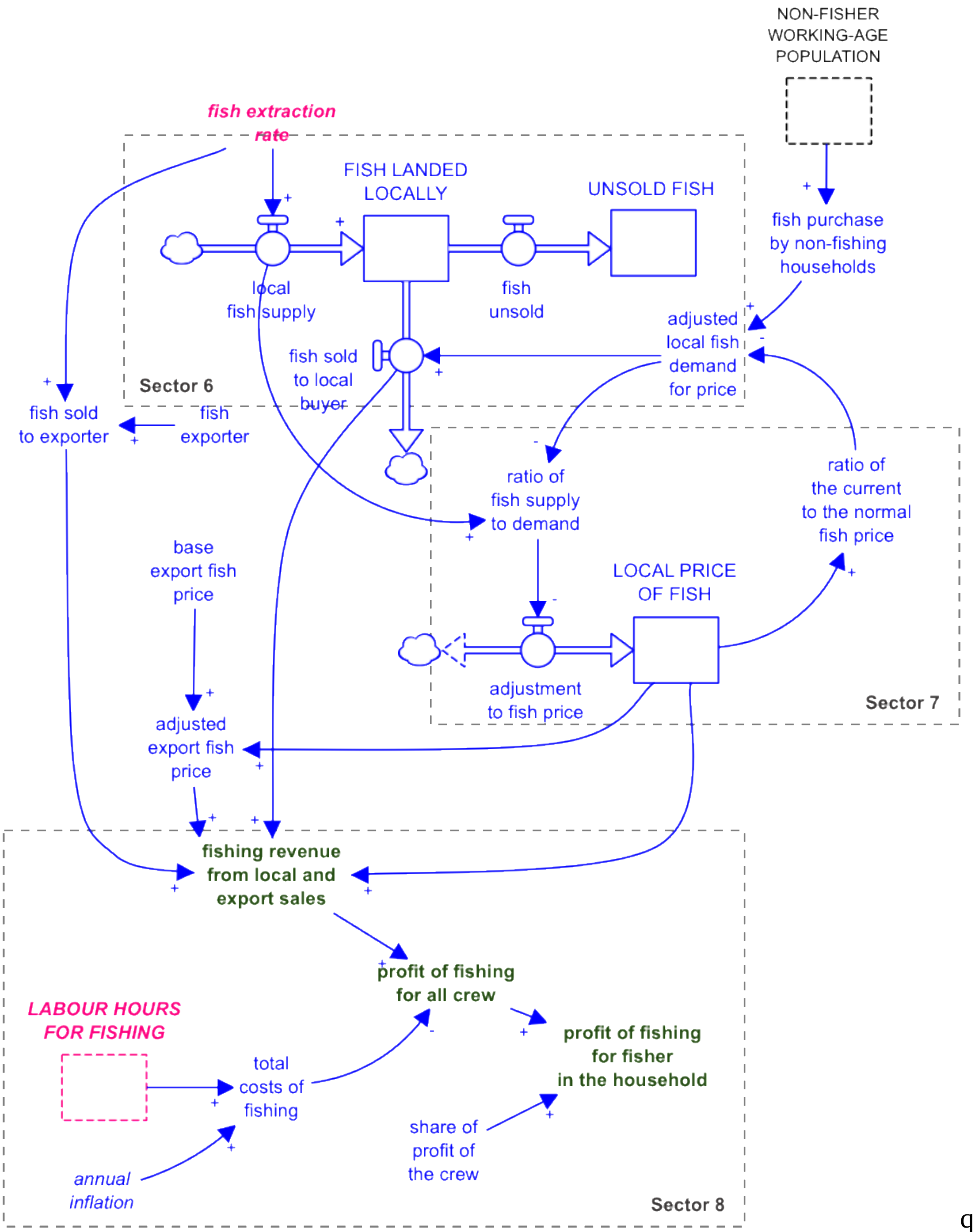

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Figure 6-3. Part two of the base case model. Stocks/flows/variables from this part that are linked to another part or parts are displayed in green. Variables inside the dashed-lined box refer to stocks originating from other parts. The sector number refers to the same sector number contained in Table 6-1 or Table 6-2. The SFD inside dashed boundary lines represents the model of the indicated sector.

6.1.2.11 Household net income/savings (Sector 13)

Sector 13 (SFD in Figure 6-4) models the *household savings* stock, which is influenced by the inflow of income from the fishing profit and outflows of savings allocated for fulfilling three financial burdens (i.e., costs of living, deficit, and debt) and two ancillary needs (i.e., costs of supplementary livelihood activity and of tertiary education). In the model, the first three spending outflows are given more priority than the latter two. The ratio of the three financial burdens determines the prioritisation of spending for the first set of three outflows, and the last set of two outflows are based on the ratio of the two ancillary needs. For the base case, fishing households were assumed to gain income only from the fishing profit since the average weekly profit of supplementary occupation was found to be significantly lower than that of fishing (see *NonFishing Input Cost Per Household Per Year* and *NonFishing Revenue per Household Per Year* variable, Appendix 17). The detailed SFD can be found in Figure 1-33 up to 1-35, and segment 13-A, 13-B, and 13-C in Appendix 18.

6.1.2.12 Household deficit level (Sector 14)

Sector 14 (SFD in Figure 6-4) models the *unrecovered deficit* information stock. The stock is a product of the current episode of the deficit (inflow) and the rate of deficit offset (outflows) using either savings (from or loan (as input to Sector 20). A deficit episode is when the current profit of fishing (i.e., weekly income) is less than the expected costs of living. The stock represents a memory of unresolved deficits from the previous weeks in addition to the current, which negatively influenced the expected costs of living (Sector 12). The stock is treated as one of the inputs for the prioritisation of household spending allocations in Sector 13. The detailed SFD can be found in Figure 1-39 in Appendix 18.

6.1.2.13 Household loan and debt (Sector 20)

Sector 20 (SFD in Figure 6-4) models the amount of *household debt* accumulated by the household. A loan principal is taken if the currently allocated savings is insufficient to offset the current deficit. For each loan, the model will apply a credit arrangement based on the randomly selected lender (three types: Section 6.1.3) which then defines the total loan value added to the debt. The credit arrangement includes interest rate per payment, number of payments within the term, loan term period, the time point when term starts and ends, and the time repayments. Debt is reduced based on the current savings allocated for loan repayment (i.e., second outflow, in Sector 13). The detailed SFD can be found in segment 20-A, 20-B, 20-C, and 20-D in Appendix 18.

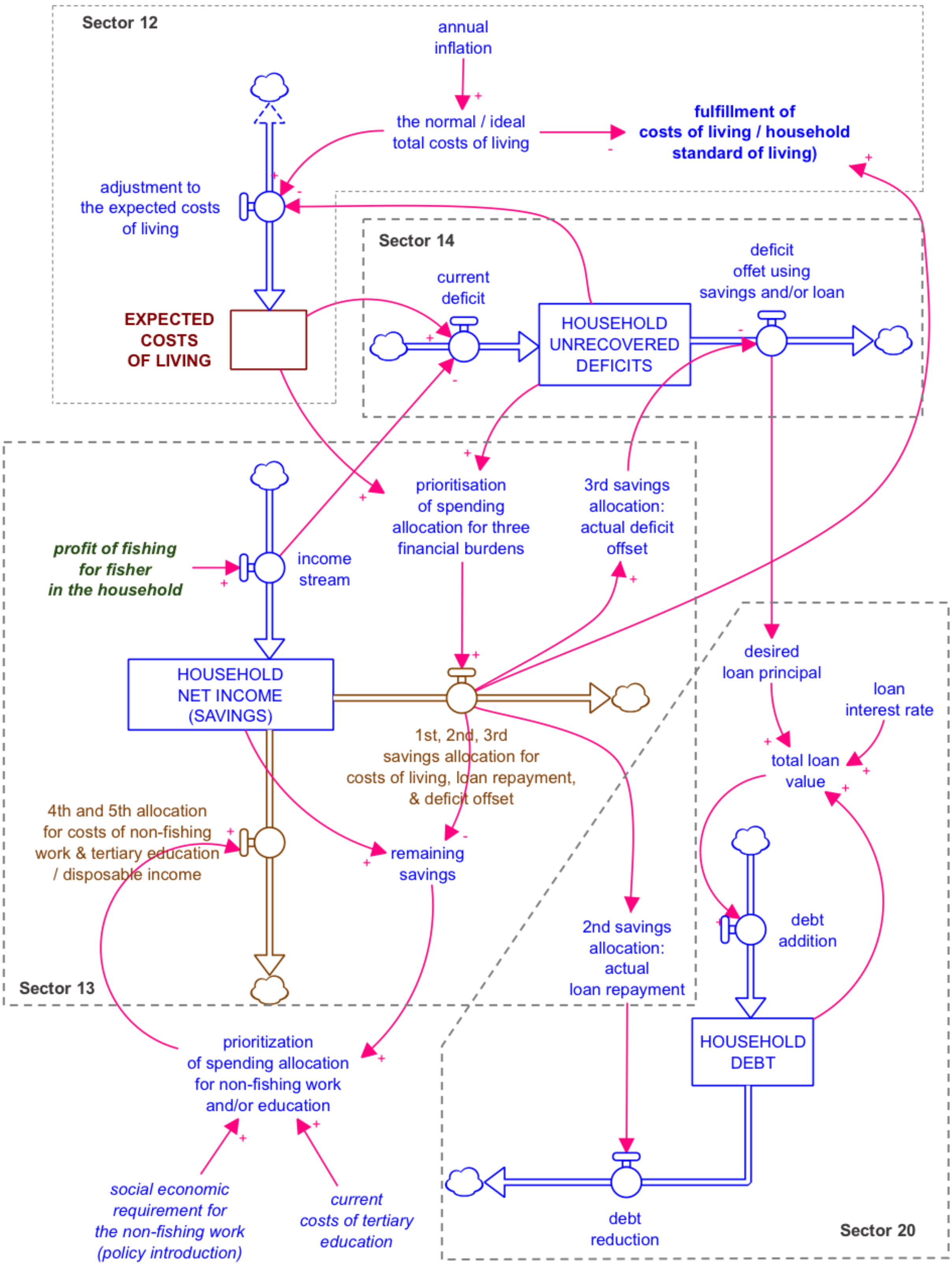


Figure 6-4. Part three of the base case model. Stocks/flows/variables from this part that are linked to other part or parts are displayed in brown. Variables inside the dashed-lined box refer to stocks originating from other parts. The sector number refers to the same sector number contained in Table 6-1 or Table 6-2. The SFD inside dashed boundary lines represents the model of the indicated sector.

6.1.2.14 Human population (Sector 16)

Sector 16 (SFD inFigure 6-5) models the human population on Selayar Island as several groups mainly comprised of *children, non-fisher working-age population, retiree,* and *fisher.* All stock was arrayed by the sex dimension. Non-fishers and fishers were arrayed by the labour age dimension. Fishers were further arrayed by the fishery group dimension. The proportion of productive female population positively influences birth rate. All stocks are positively influenced by the migration rate (i.e., immigration or emigration and thus, as bi-flows), and negatively by the death rate (outflows). The non-fisher and fisher stocks represent the local labour force, in which there is a movement of fisher entries and exits between the two stocks, influenced by several determinants modelled in Sectors 18 and 19. In the detailed SFD, the fisher stocks are also linked to a bi-flow represent fisher movement between fishery groups that are modelled in Sector 17. For the base case, population-related parameters (including Sector 17) were largely estimated based on the annual demography statistics reports issued by the local government. The detailed SFD can be found in Figure 1-41 to 1-47 in Appendix 18), which also includes the movement of fishers between the fishery group.

6.1.2.15 Fishery groups (Sector 17)

Sector 17 (SFD in Figure 6-5) models the movement of fishers between three fishery groups related to the array dimension in Section 6.1.3, including:

1. 'Traditional' fishers: Fishing households with at least 50% of fishing trips in the nearshore area using a boat with either no or smaller engine (e.g., ≤10 HP, or the 'motorised' boats) or larger engine (e.g., >10 HP, or the 'non-/smaller motorised' boats).
2. 'Destructive' fishers: Fishing households with a similar profile as the Traditional but predominantly relying on blasting fishing or cyanide/poison fishing methods.
3. 'Squid/pelagic' fishers: Fishing households with a similar profile as the Traditional but with at least 50% of fishing trips in offshore (pelagic) area or inshore but using mobile lift-net boats or 'bagang'.

Each fishery group is represented by a stock that is arrayed by the sex and labour age dimension. The number of fishers in each stock's dimension elements mirrors those in the human population sector. Thus, each stock is also influenced by the same rate of fisher entries (inflow), of fisher exits (outflow), of deaths (outflow), of migration (bi-flows), and of movement between age group mirroring (bi-flows). The stocks are linked to each other using bi-flows that model the fisher movement between each of the fishery groups. The detailed SFD can be found in Figure 1-48, 1-49, and 1-50 in Appendix 18.

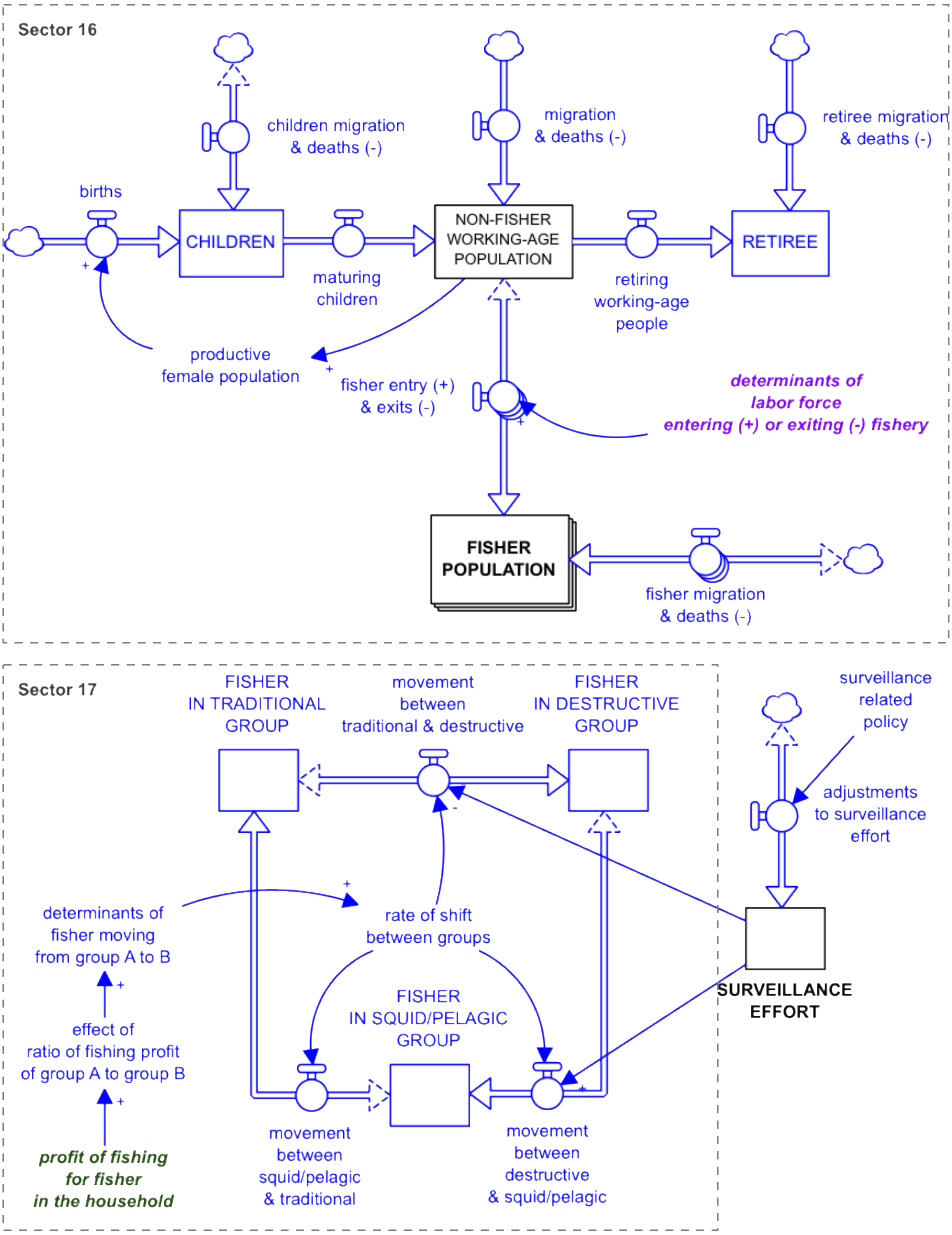


Figure 6-5. Part four of the base case model. Stocks/flows/variables from this part that are linked to another part or parts are displayed in black. Variables inside the dashed-lined box refer to stocks originating from other parts. The sector number refers to the same sector number contained in Table 6-1 or Table 6-2. The SFD inside dashed boundary lines represents the model of the indicated sector.

6.1.2.16 The effort for non-fishing occupation by fishers (Sector 10)

Sector 10 (SFD in Figure 6-6) models the fisher's average remaining effort for non-fishing work (i.e., supplementary occupation) based on the labour hours after the uptake of the average maximum weekly labour hours for fishing. In the detailed model, the non-fishing effort is negatively influenced by the ration between the profit of fishing to non-fishing work (in any) and the opposite influence on the fishing effort (modelled in Sector 9). Fisher's available effort for non-fishing serves as one of the inputs to the total non-fishing labour hours available in the household (Sector 11). The detailed SFD can be found in Figure 1-28 in Appendix 18.

6.1.2.17 The effort for non-fishing occupation by non-fishers (Sector 11)

Sector 11 (SFD in Figure 6-6) estimates the total effort for the non-fishing work available in the household based on the labour hours sourced from the unemployed working-age household members and non-fishers and the fisher in the community. The model also applies a limit to the ability of fishing household/fisher to outsource labour external to the households, which reflects the boundary of social interaction of each FH, which are restricted to a particular social network of their fishing groups (i.e., village-based). To model this, labour hours from the community are negatively influenced by the number of fishers/fishing households in the population/community. The detailed SFD can be found in segment 11-A and 11-B in Appendix 18.

6.1.2.18 Profit of non-fishing work (Sector 21)

Profit of non-fishing work (i.e., supplementary occupation in the households) was excluded from the base case model and thus treated as a policy mode. The sector is discussed more extensively in the policy modelling chapter, in Section 7.1.2.

6.1.2.19 Household tertiary education capacity (Sector 15)

Sector 15 (SFD in Figure 6-6) models the period of time when the household is able to finance, at least, one labour age household member for undertaking higher education (i.e., transitioning to a job outside the island) and therefore, migrate out of Selayar. The model uses an information stock that counts the weeks when the fifth savings allocation outflow (from Sector 13) is above the required weekly tertiary education costs. The stock level is then positively influencing the rate of fisher entry and exit in Sector 16 and 17, and of the emigration in Sector 16. The detailed SFD can be found in Figure 1-40 in Appendix 18.

6.1.2.20 Determinants of fisher entries and exists, the inter-fishery labour movement, and fishing effort (Sectors 18 & 19)

Sectors 18 and 19 (SFD in Figure 6-2 and Figure 6-6), models the adjustment of the rate of inter-fishery movement / IFM (in Sector 17); and of (2) fishers' entries and exits / FEX (in Sector 16); and of (3) the fishing effort / FE (in Sector 9). The IFM from, for example, group A to B is positively influenced by the ratio of the weekly fishing profit of A to B (Sector 8). FEX are positively influenced by the ratio between the profit of fishing (Sector 8) and non-fishing occupation (if exists, Sector 21), and the maintenance of tertiary education financing (Sector 15). Both the IFM of the destructive group to the other two groups and the average FE of the destructive group are also negatively influenced by the surveillance index (as stock) that is, similar to non-fishing work profit, modelled as a policy in Chapter 7 (Section 7.1.4). The IFM is also positively influenced by the employment demand in the fishery that was estimated by the ratio of current fisher and boat availability. The FE is also negatively influenced by the seasonal weather-related disruption, and positively by the profitability of fishing in fulfilling the expected costs of living. The detailed SFD can be found in segment 18-A, 18-B, 19-A, 19-B, 19-C in Appendix 18.

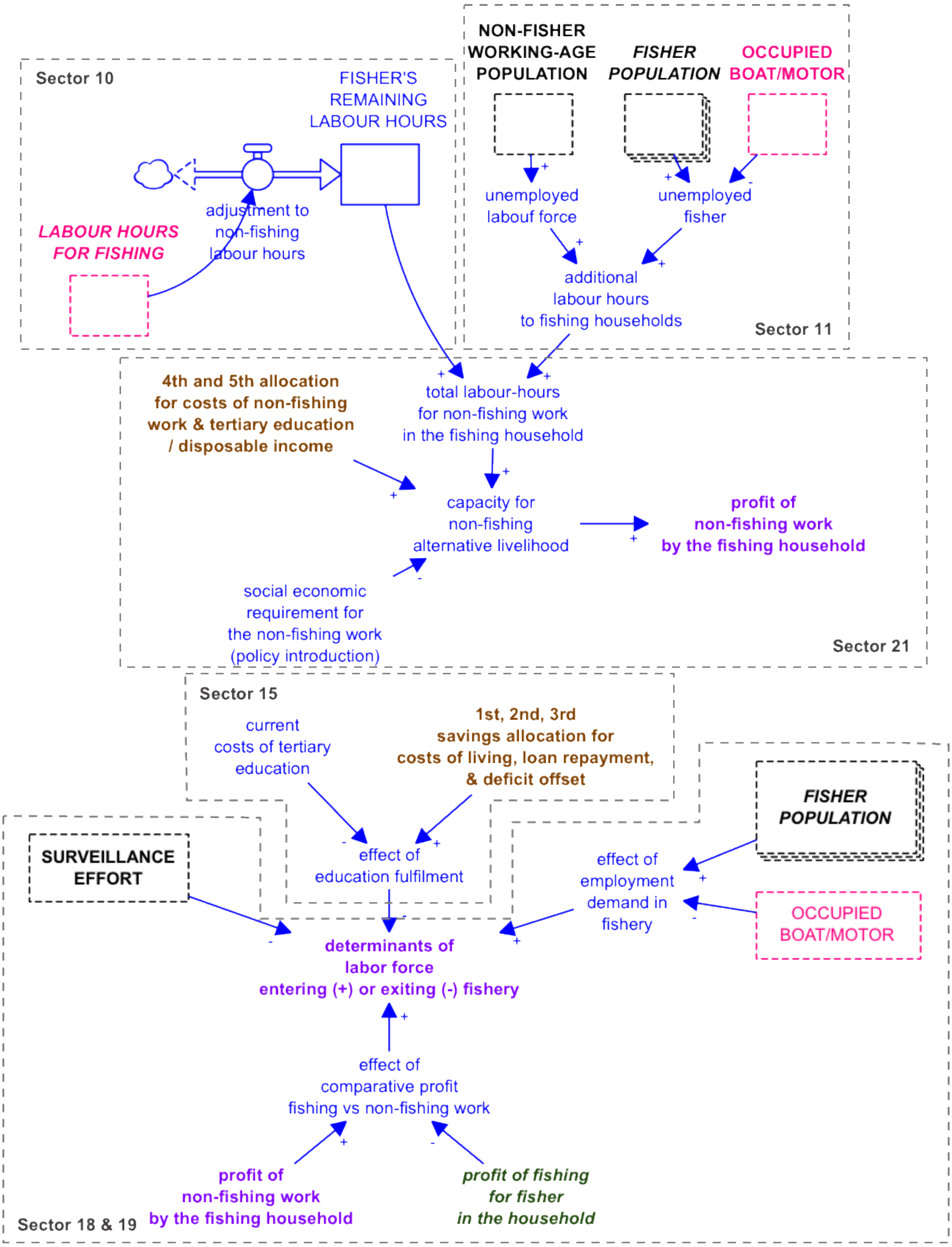


Figure 6-6. Part five of the base case model. Stocks/flows/variables from this part that are linked to another part or parts are displayed in purple. Variables inside the dashed-lined box refer to stocks originating from other parts. The sector number refers to the same sector number contained in Table 6-1 or Table 6-2. The SFD inside dashed boundary lines represents the model of the indicated sector.

6.1.2.21 Excluded variables

Some of the internally influencing variables from CLD 3 were excluded from the 'base case' (Section 6.1.2) stock-and-flow model (and therefore, any associated direction of influences) including*: fishing activity by non-Selayar fisher, collective effort on learning non-fishing work, non-fishing work effort, non-fishing work costs ,and non-fishing outputs.* The latter three variables were later assessed as one of the policies tested in Chapter 7. The excluded exogenously influencing variables include: *age-related unfitness* and *risk-averse behaviour*. The base case model structure, model testing, and output behaviours are presented later in Sections 6.2, 6.3, and 6.4.

The *fishing activity by non-Selayar fisher* variable was excluded from the base case, mainly due to the lack of pre-existing information that could help develop its parameter assumptions at the time of the study. However, since the variable was still considered to be a crucial part of the system by the problem stakeholders (i.e., in the problem scoping: *purse-seine boats*, Table 4-4, in the problem mapping: *external larger fishing vessels*: Figure 5-6), it was later assessed in the dynamic modelling separately using the 'alternative base case' (ABC) stock-and-flow model. Section 6.5 presents more backgrounds on the separate modelling of this effect, and the additional structure, parameter, and output behaviours associated with the ABC model.

6.1.3 Array dimensions in the stock-and-flow model

The description of the array dimensions applied in the variables in the detailed SFD in Appendix 18 is listed in Table 6-3. The proxy data/information used to estimate the parameter for the dimension element can be found directly under the parameter description of the associated variables, which can be found in the table of input values assigned in the constant converters in Appendix 23.

Table 6-3. The list of array dimensions applied to the SFD elements, and the label and description of each dimension elements. Elements were mostly labelled using acronyms to differentiate between dimension name and element name in the Stella® equations in Appendix 19 to Appendix 23.

No.	Array dimension group name	Dimension element labels	Element descriptions
1	Boat Motor	EN	Operating fishing boat with large motor installed
		NEN	Operating fishing boat without a motor, or with motor below 5 horsepower
2	Consumer	FHH	Fish consumers from fishing households
		NHH	Fish consumers from non-fishing households
3	Financial Burden	Cost of Living	Net income allocation for costs of living
		Debt Clearing	Net income allocation for loan repayments

No.	Array dimension group name	Dimension element labels	Element descriptions
		Deficit Offset	Net income allocation for offsetting a deficit
4	Fish Class	HR	Commonly-sold fish from the herbivorous trophic level (e.g., parrotfish)
		PR	Commonly-sold fish from the carnivorous trophic level (e.g., coral groupers)
		SQ	Commonly-sold fish from the fast-reproducing or pelagic-inhabiting fish group (e.g., squids and anchovy)
5	Fishery Group	TR	Nearshore small-scale enterprise fisher relying on artisanal fishing methods or ‘traditional fishers’
		DS	Traditional fishers that use destructive method mainly of blast and cyanide fishing, or ‘destructive fishers’
		SF	Offshore small-to-medium scale enterprise artisanal fisher, or ‘squid/pelagic fishers’
6	Habitat Type	SG	Seagrass fish habitat/fishing ground
		RF	Coral reef fish habitat/fishing ground
		PG	Pelagic/off-shore area fish habitat/fishing ground
		MN	Mangrove fish habitat/fishing ground
7	Labour Age	YN	Young working-age population category
		MD	Middle working-age population category
		OL	Older working-age population category
8	Lender Type	Informal Flex	An informal lender with a flexible credit arrangement (e.g., relatives, friends, household member).
		Informal Pred	An informal lender with an exploitative credit arrangement (e.g., shark loan, fisher’s patron, *punggawa*)
		Formal Flex	A formal lender with income-dependent credit arrangement (e.g., bank).
9	Mangrove Size	SM	Small mangrove tree category
		LG	Large mangrove tree category
10	Sex	FM	Female population category
		ML	Male population category

The array diagram in Figure 6-7 summarises the arrangement of array dimension (i.e., text in red boxes, text in square brackets) applied to the sectors (i.e., text in black boxes) and to the components or processes (i.e., text without box). Array dimensions in bold text indicate that the sector is where the array is introduced. Numbers inside the round bracket and the numbered list indicate the number of elements for the dimension and the element names, respectively. The arrows indicate the directions of influence similar to the description in Figure 6-1, where some influence involves simulating the movement of materials from a sector/variable into another sector/variable with different array dimensions (arrows in bold line) and thus, re-arraying[14] is performed. In the Stella® equations (e.g., Appendix 19 to Appendix 23), array dimensions or dimension elements are indicated by the texts inside square brackets.

[14] About array dimensions and elements in the stock-flow model: 3.6.5.1.

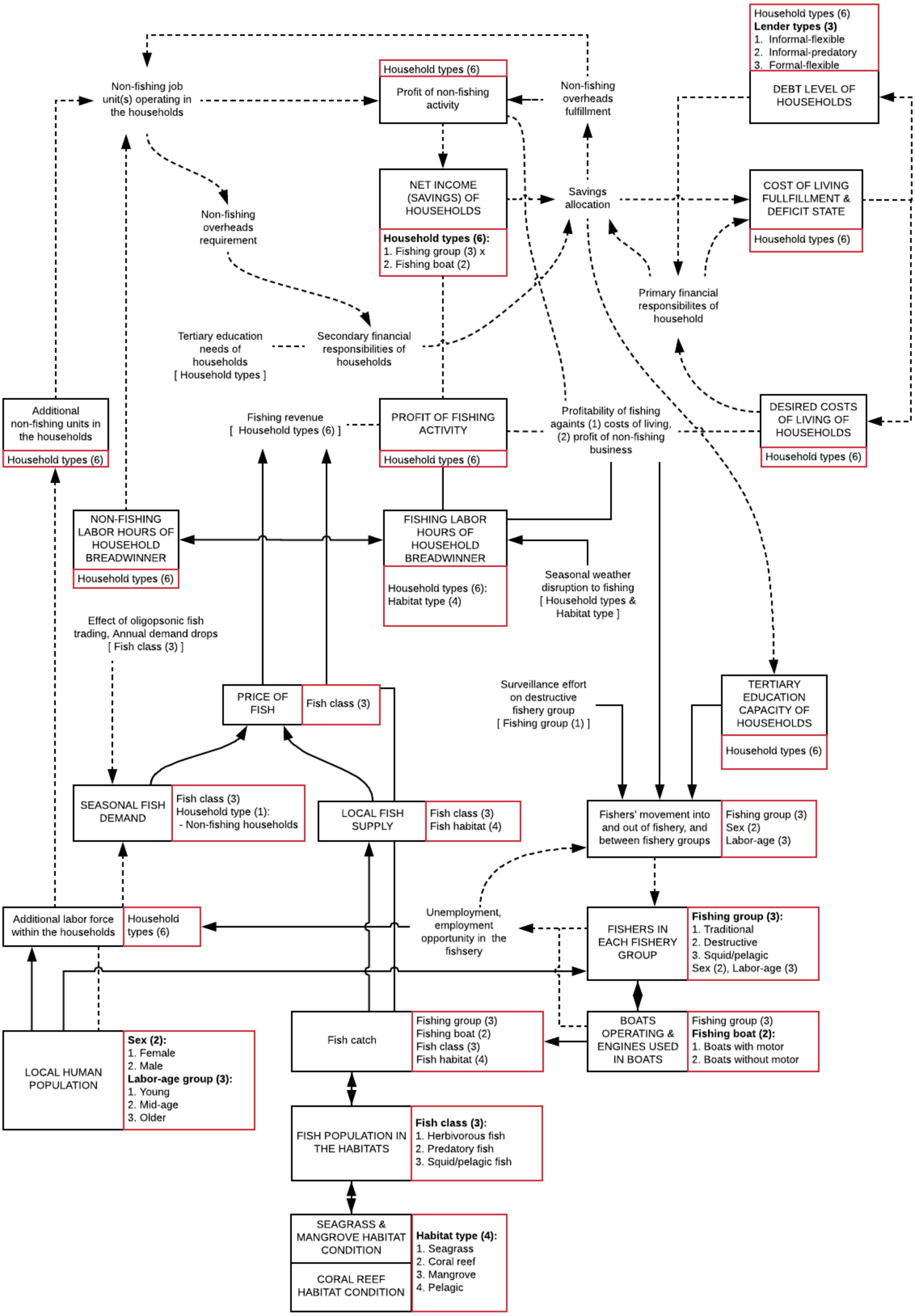


Figure 6-7. Array dimension diagram.

6.2 Result 2: Model parameters to simulate the base case condition

6.2.1 Simulation time horizon, delta time, and integration method

The time unit of the simulations was set as weeks, and accordingly, parameter input values are adjusted to reflect the 'average' weekly conditions. The time horizon of the simulation was limited to 30 years with a model start time of 0 (i.e., year 0 is assumed as the year 2016) and end time of 1586 (i.e., assumes one year is equal to 52 weeks). The delta time was 0.25 (1/4) meaning that the simulation runs discrete computations at the interval of a quarter of a week. Given the small DT, the chosen integration method was 2nd-order Runge-Kutta[15] since it avoided significant value rounding errors that would be introduced when using Euler's method. These settings were considered as a 'good compromise' as they reproduced the simulation behaviour of a smoothly continuous system and generated the logical conditional rule parameters (e.g., IF, THEN, ELSE built-ins) without slowing down computation performance of the portable computer that I was using.

6.2.2 Stella® equations and input values contained in the model elements (Appendices)

The documentation of the model equations is organised into several groups, each of which can be found in the Appendix, and which include:

1. Equations contained in the converters, flows, and stocks (in Appendix 19, Appendix 20, and Appendix 21, respectively) are expressed using standard mathematical operators[16], built-in commands[17], and the names of the input variables.
2. Equations, graphical points (*x*-coordinate, *y*-coordinate) and the graphs in the graphical function converters[18] (in Appendix 23). Graphical converters were used to represent a dimensionless multiplier effect that reflects the positive/negative influence of a variable to another (henceforth referred to as 'dimensionless multiplier'). The multiplier value (i.e., the output of the converter) were used largely to reflect the influence of a ratio-based change

[15] The software simulates stock change over time using discrete computations that uses 2nd- order Runge-Kutta algorithm to compute values for flows given the estimate for the change in corresponding stocks over the interval DT. About integration method: https://www.iseesystems.com/resources/help/v1-6/default.htm#08-Reference/05-Computational_Details/Overview_Computational_Details.htm#kanchor971

[16] About operators: https://www.iseesystems.com/resources/help/v1-6/default.htm#08-Reference/07-Builtins/Operators.htm#kanchor26

[17] About built-in functions: https://www.iseesystems.com/resources/help/v1-6/default.htm#08-Reference/07-Builtins/Overview_Builtins.htm

[18] About graphical functions: https://www.iseesystems.com/resources/help/v1-6/default.htm#08-Reference/01-ObjectsAndProperties/03-InputObjects/GraphicalInput.htm#kanchor55

(e.g., between current and initial condition/value) of a variable (as input) to the dependent variable.

3. Initial input values reflecting the normal condition in the stocks, constant value converters, switch converters, and calibrator converters (in Appendix 22, Appendix 23, Appendix 25, Appendix 26, respectively).

6.3 Result 3: Outputs from model tests

6.3.1 Unit consistency & integration error test results

Unit inconsistencies had been identified automatically by the Stella® Architect software. However, after applying the unit description to variables without units (i.e., dimensionless) and assigning the time unit for level values that should be rate values (or the other way around), unit inconsistency warnings were no longer being displayed by the software. Furthermore, minimal differences had been noticed when changing integration methods, such as between the Euler and Runge-Kutta integration methods built into the software. However, the team considered this to be negligible since the two methods would still produce similar behaviour-over-time results at the temporal resolutions (monthly, yearly, decadal, and throughout the time horizon) used in the analysis.

6.3.2 Mass-balance test results

Model sectors that include flow chains (i.e., one or several stocks linked to more than one flows) were tested for the conservation of mass (i.e., materials simulated in the stocks). These test results can be found in Appendix 27, which overall shows that the sectors have a balanced mass since the model assumes that the system is closed as it represents only the boundary of the system of interest (CLD 3). A balanced conservation of mass were indicated in the sectors by the zero gaps between the total materials added to the system and the total reserved in and outflowing from the system. However, a negative mass balance was identified in the fish population sector and not resolved until the finalisation of this manuscript (see Fish Population sector in Appendix 27). Yet, the negative gap is extremely small given its fluctuation within a decimal range of 0 to 2 fish individuals 'leaking out' of the system per week. Thus, although unresolved, the team considered the model defect it acceptable as its impact in altering the dynamics of the stocks is very minimal and unnoticeable in the system behaviour over time.

6.3.3 Extreme condition test results

In general, plausible/realistic response behaviour was generated when extremely high and/or zero input parameter values are applied in the middle of the simulation period. In some tests, this verdict came after revisions were made in the equations. Tests were conducted only on SFD sectors simulating the base case condition, thus sectors related to the tested policies (e.g., non-fishing activity) were excluded. The tests of some parameter variables (first-tier) might adjust the subsequent-tier variables to zero or an extremely high value. Thus, the subsequent variables were skipped from the test as the influence directly reflects a test and due to limited working time. The test results can be found in Appendix 28.

6.3.4 Sensitivity test results

The observed output variables and the policy parameter variables (about: Section 3.6.5.3.5) included in the sensitivity tests are listed in Table 1 and Table 2, respectively, in Appendix 29. Tornado diagrams visualising the sensitivity of each output variables are also contained in the same appendix. Analysis and discussion associated with the test are related to the policy assessments and therefore, are elaborated in Chapter 7. Due to limited working time and the number of variable replications from the dimension, parameter input adjustment and output variable observation were only conducted to single dimension element that represents each array dimension Table 6-4).

Table 6-4. A list of the dimension element that represents each array dimension in the sensitivity tests. The description of the elements follows Table 6-3.

No.	Array dimension group name	Dimension element examined in the model testing / Code
1	Boat Motor	Boat with larger motor / EN
2	Fish Class	Predatory fish class / PR
3	Fishery Group	Traditional fishers/ TR
4	Habitat Type	Coral reef / RF
5	Labour Age	Young working age / YN
6	Lender Type	Informal-and-predatory lender / INF.PRED.
7	Sex	Male / ML

6.4 Result 4: Reproduction of system behaviours in the reference modes using the 'base case' model

This section presents the results from behaviour reproduction tests (Section 3.6.5.3.6) organised into subsections of each that are dedicated to the state variables conceptualised in CLD 3 (Table 6-1). In the subsections, the simulated output behaviours were generated using the base case model structure and parameters (Sections 6.1, 6.2, respectively).

6.4.1 Initial parameter value adjustments and model spin-up time

After the parameterisation was completed, several parameter input values needed to be adjusted to avoid a 'ringing' artefact. This was applied particularly input parameters that are dimensionless in their influence on another variable (e.g., fish supply to fish demand), which is regulated using the graphical functions (Appendix 23). The ringing involves spurs of unrealistic near-zero or extremely-high output value generated by initial parameter input values that are either too low or too high. The likely causes for this behaviour are that the initial input values (i.e., current normal conditions) and the graphical function (i.e., the dimensionless relationship between the input and an output variable) are derived from different data sets or sources of information. ‘Calibrator’ converters were prepared in the SFD that perform multiplicative adjustments to the parameter values, which are listed in Appendix 26.

This intrinsic limitation in the parameterisation was also suggested to have implications for the ratio-based effect that defines almost all of the dimensionless relationship in the model. For example, although the change in the ratio of the current to the initial value of variable *A* that has a multiplier effect to variable *B*, yet an equal ratio of variable *A* does not necessarily reflect the ‘normal’ level relationship of variable *A* to variable *B* at its ‘normal’ value. This condition was seen as a possible explanation for the model ‘spin-up’ that occurred between the first quarter and the first half-year of the simulation. During this period, a number of parameter variables experienced extreme initial value spikes or dips that presumably ended when the model reached a state of statistical equilibrium under the applied combination of multiple ratio-based effects in the simulation.

Accordingly, simulation outputs during the initial spin-up time were considered unreliable and excluded in the analysis. Hence, in the next subsections, system behaviours presented in the line graphs are presented starting from the output of week 26 or after the first 6 months. Simulation end time is also added 26 weeks to set the 30-year time horizon.

6.4.2 System behaviours reproduced using the ‘base case’ stock-and-flow model

In this section and henceforth, the term ‘expected trend’ or ‘desired trend’ refers to the trends of the identified variables after the Round Two problem-mapping FGD (state variables: Table 5-6, all variables: Appendix 12). Abbreviations in the graph legends refer to the dimension element name as described in Section 6.1.3.

6.4.2.1 Coral reef and other fish habitat conditions

6.4.2.1.1 Mangrove

Referring to Figure 6-8, the mangrove forest area was projected to remain steady and therefore, similar (all else being equal) in terms of mangrove carrying capacity for juvenile and adult fish of all fish groups. The outcome is anticipated since the model parameter assumes an optimistic condition where mangrove area in Selayar are not influenced by the fishing activities and thus, unchanging and constantly supplying fish to the system.

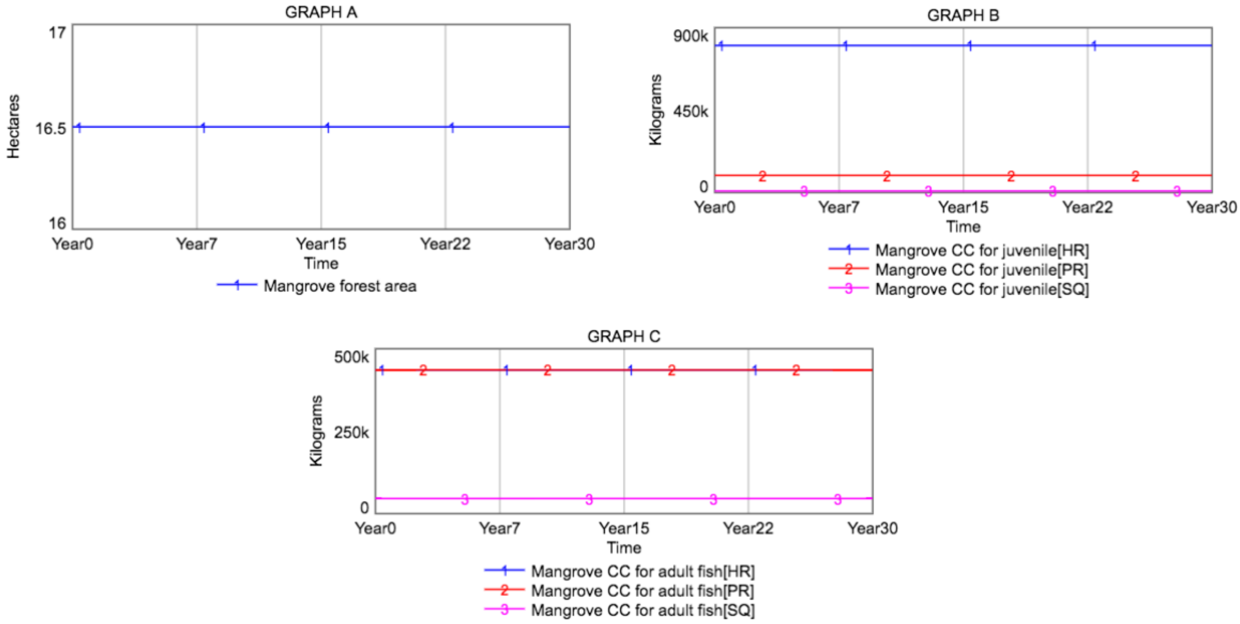


Figure 6-8. Mangrove forest area (graph A), mangrove carrying capacity for juvenile fish (graph B), mangrove carrying capacity for the adult fish (graph C).

6.4.2.1.2 Seagrass

Referring to Figure 6-9, the above-ground seagrass area is expected to decline steadily and therefore, reduce its carrying capacity for juvenile and adult fish of all fish groups over time. The decline is caused by weekly mortality of the above-ground seagrass area due to chemical damage from cyanide fishing (Figure 6-10). The magnitude of area loss varies in each week reflecting the randomly generated values of seagrass mortality delay between the specified minimum and maximum range. The outcome behaviour less-desirable as it is contrary to the future trends perceived by the majority of the villagers who predominantly expect that seagrass condition and the cyanide fishing will remain steady. Yet, these output behaviours are likely plausible given the exclusions of influences that may suppress destructive fishing such as surveillance.

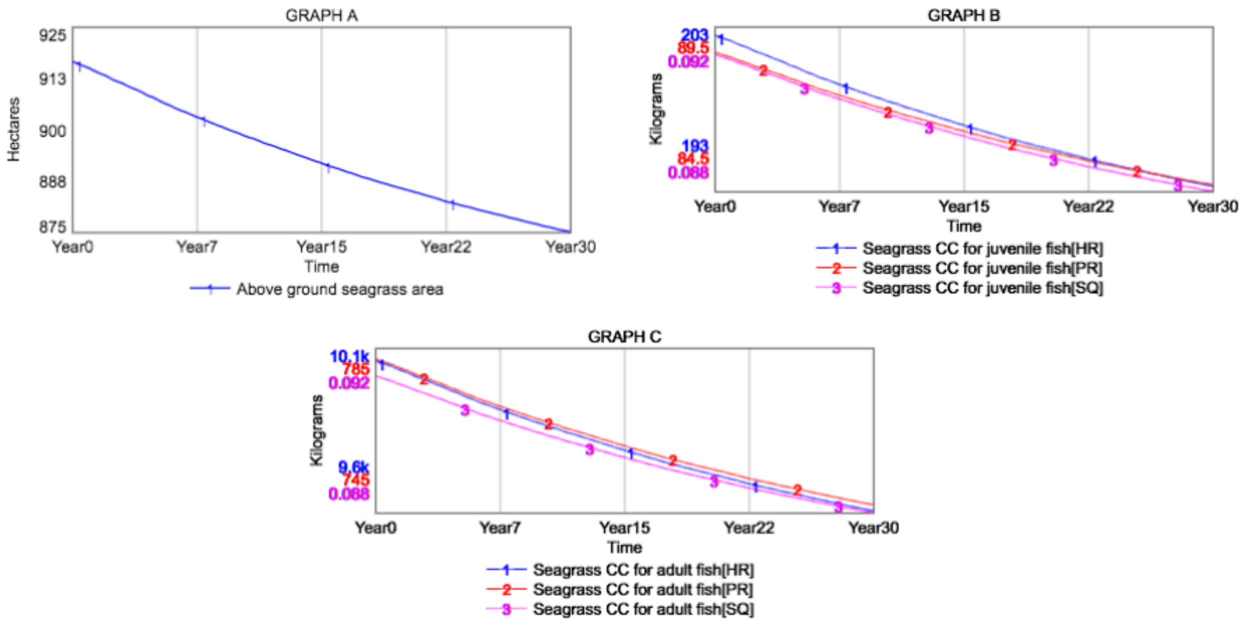


Figure 6-9. Above ground seagrass area (graph A), seagrass carrying capacity for juvenile fish (graph B) and for adult fish (graph C).

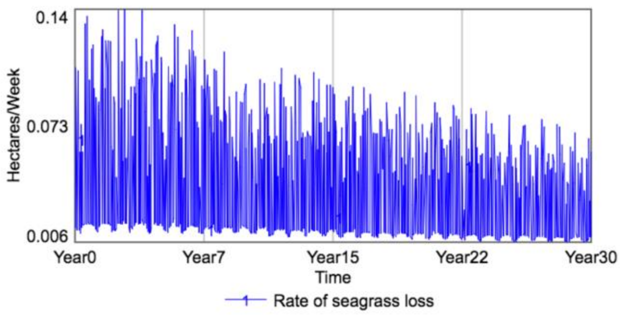


Figure 6-10. The rate of above-ground seagrass loss.

6.4.2.1.3 Coral reef

Referring to Figure 6-11, the area of reef with the living coral substrate is projected to decline steadily (graph A). The decline is caused by the weekly conversion of the living substrate area into rubble due to destructive fishing (A, Figure 6-12) where the area is gradually declining. These trends agree with the projected future trends of *coral reef* and *bomb fishing:* that it was expected to decline gradually. Despite the decline, the reef carrying capacity for both juvenile and adult fish is projected to increase steadily (graph B, Figure 6-11) since the weekly fish supply from reef rubble area is steadily increasing as the rubble area is increasing in size (Figure 6-13). This may be due to the fact that at this stage, the model does not apply the influence of the change in the index of reef condition to the carrying capacity of the rubble area, unlike the living substrate area. Similarly, the model projected that the index of reef condition in the remaining living substrate area is improving (graph C, Figure 6-12). This can be attributed to the level of the population of herbivorous reef fish supplied from the rubble area that is still maintaining the reef grazing, and to the assumption that water quality (i.e., total suspended solids concentration) remains stable over time (i.e., minimal sedimentation or pollution in the water column).

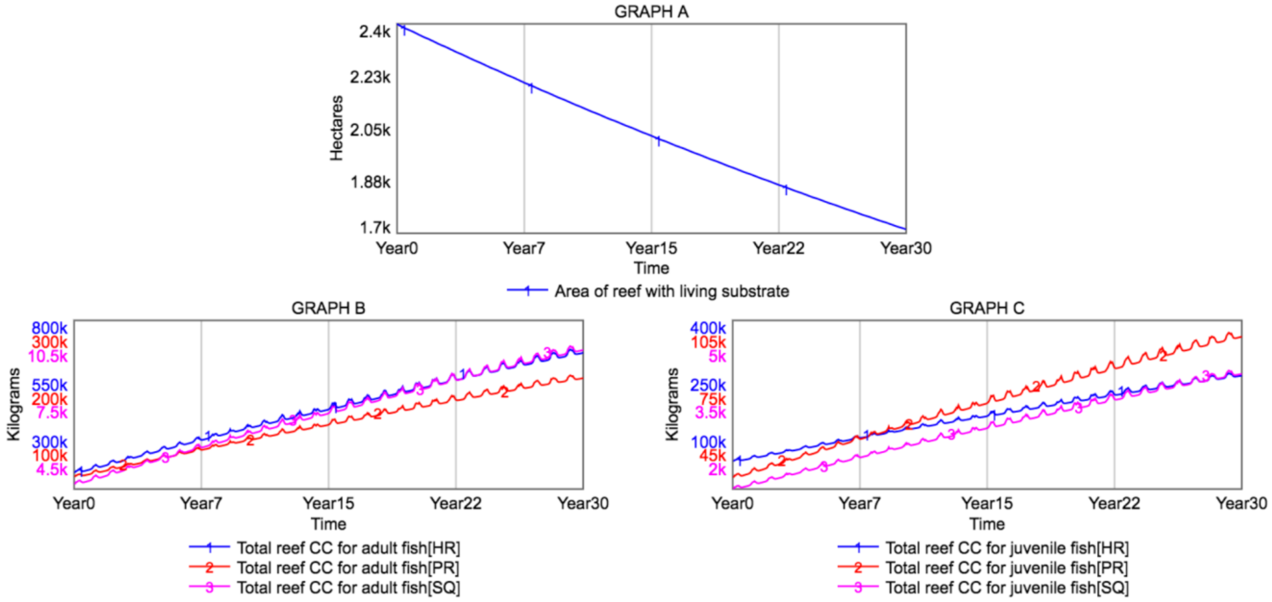


Figure 6-11. Area of the reef with the living substrate (graph A), Carrying capacity of the coral reef for juvenile (graph B) and adult fish (graph C).

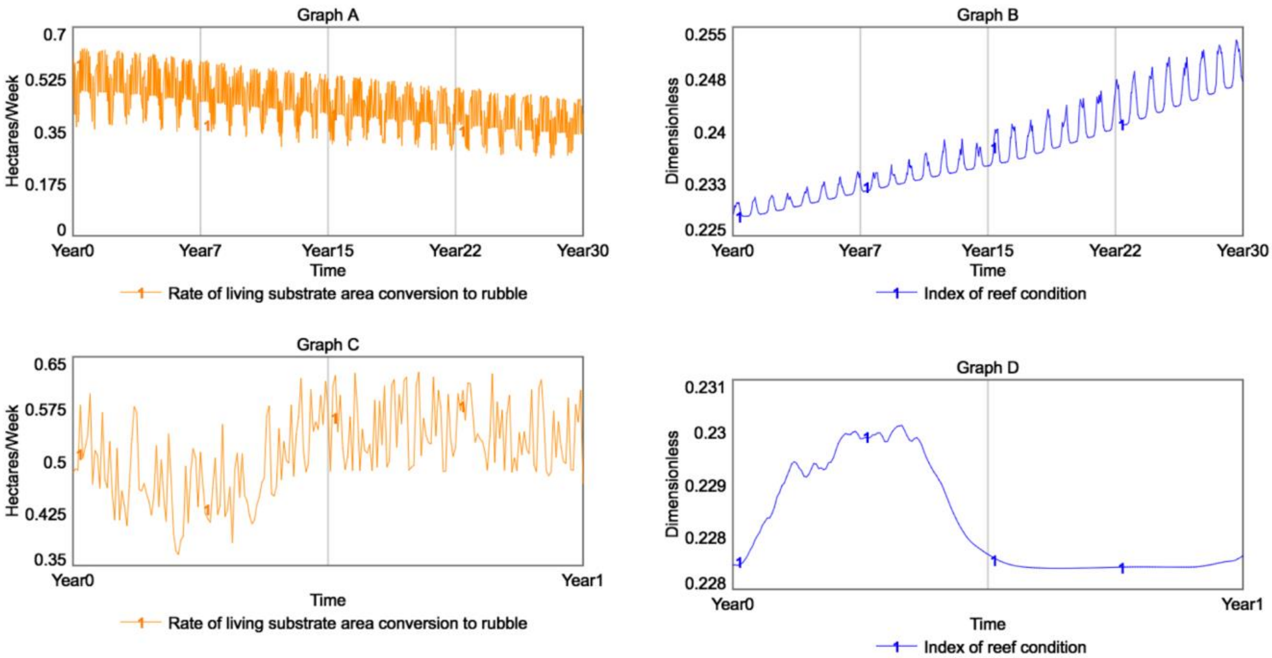


Figure 6-12. The rate of living substrate conversion to rubble in 30-year and one-year resolution (graph A & C, respectively), index of reef condition in similar resolutions (Graphs B & D, respectively).

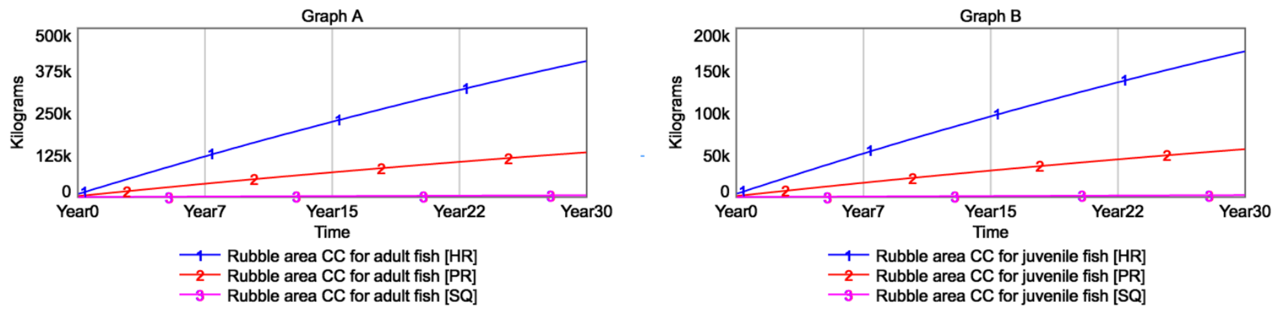


Figure 6-13. The carrying capacity of the reef rubble area for the adult (graph A) and juvenile fish (graph B).

6.4.2.2 Local fish population

As shown in Figure 6-14, the population of juvenile fish in all fish groups is projected to increase steadily over time; and a similar trend is expected for the adult fish population (Figure 6-15). These 'macro' trends contradict the estimated trends for the *fish* variable, which was perceived by the community to be either remain stable or gradually declining, but consistent with the desired trends. This desirable outcome is expected since the model assumes no direct impact by the fish harvest on juvenile stock since the rates of catch are imposed only on adult fish.

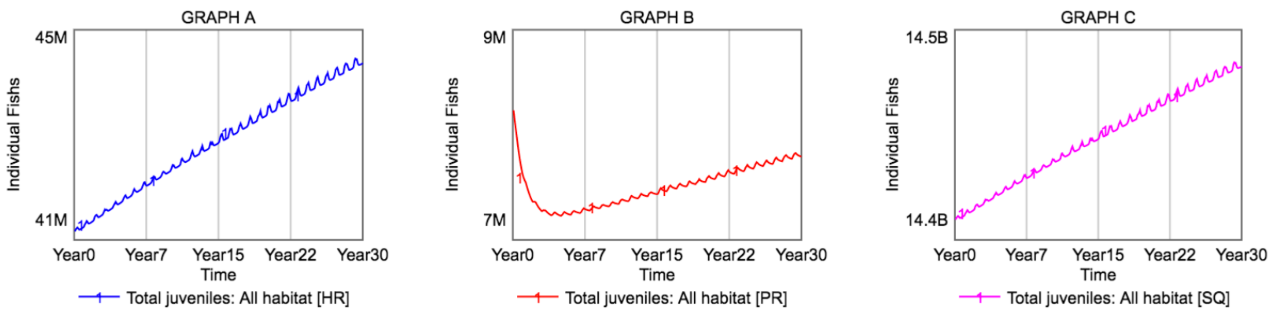


Figure 6-14. The total population of the juvenile herbivorous (graph A), predatory (graph B), and squid/fast-reproducing fish groups (graph C) from all four habitats.

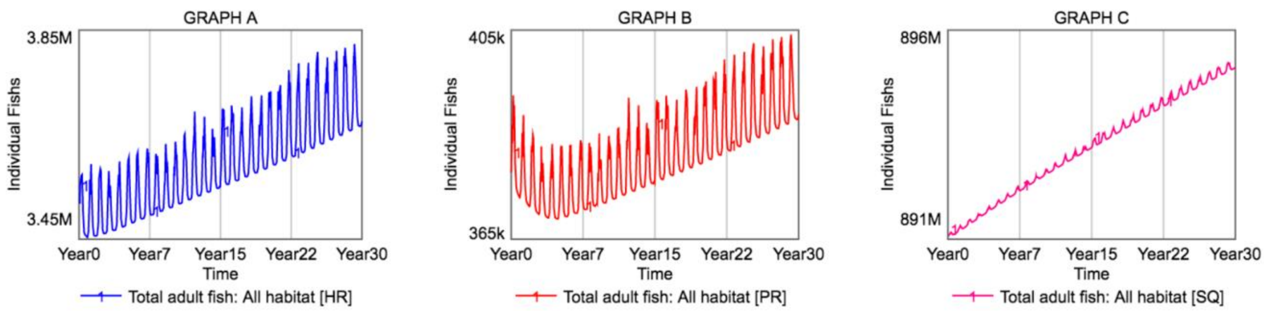


Figure 6-15. The total population of the adult herbivorous (graph A), predatory (graph B), and squid/fast-reproducing fish groups (graph C) from all four habitats.

However, looking at each of the four habitat categories, the fish stock trend of each fish class differs from one fish class to another. As shown in Figure 6-16, adult fish stocks in mangrove and pelagic habitats remain stable over time (MN, PG) with the exception of that of the pelagic predatory fish, which gradually increases. Fish stock in the coral reef (RF) gradually increases and, however, the trend in seagrass (SG) is gradually declining. Fish trends for MN and PG are expected since the model assumes that the carrying capacity for fish by mangrove and pelagic habitats remains fixed over time. The decline in SG might be attributed to the rate of fish catch, which is high enough to reduce the portion of the reproductive adult and, therefore, lower the rate of juvenile fish addition/recruitment. And the opposite condition may explain the fish increase in RF.

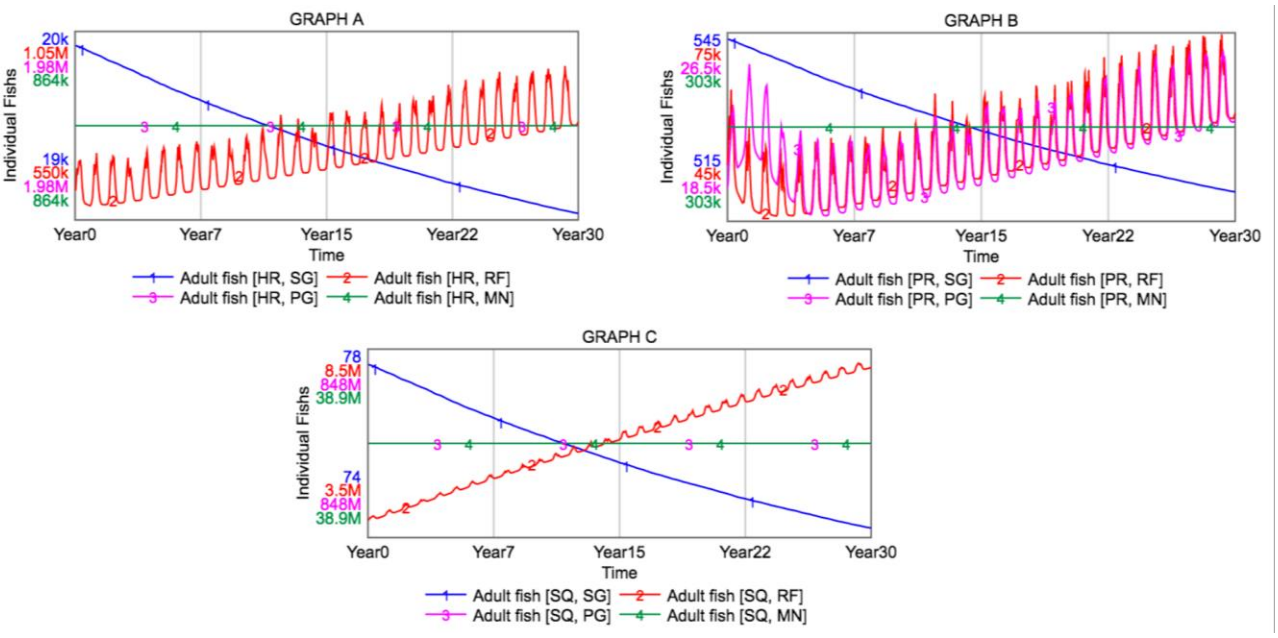


Figure 6-16. The total population of the adult herbivorous (graph A), predatory (graph B), and squid/fast-reproducing fish groups (graph C) in each habitat.

6.4.2.3 Fish catch

Referring to Figure 6-17, in general, the weekly total fish catch generated by the traditional and destructive group is estimated to increase steadily, while a gradual decline will be experienced by the squid/pelagic group. Despite the increasing wild fish availability, the total rate of fish catch from the three habitats is likely to decrease gradually, with the exception of the coral reef, which is projected to increase gradually (Figure 6-18). This dissimilarity is analogous to the estimated future trend of *fish catch* that was bimodal at either gradually declining or increasing (the former was more dominant). In all fisher groups, the motorised boat sub-groups will maintain a much higher weekly total fish catch likely compared to the non/smaller-motorised boat group (Figure 6-19). This trend is anticipated given the proportion of motorised boat is set to be higher than the non/smaller-motorised boats, and the model did not take account of fisher shifting between boat groups in the same fishery group.

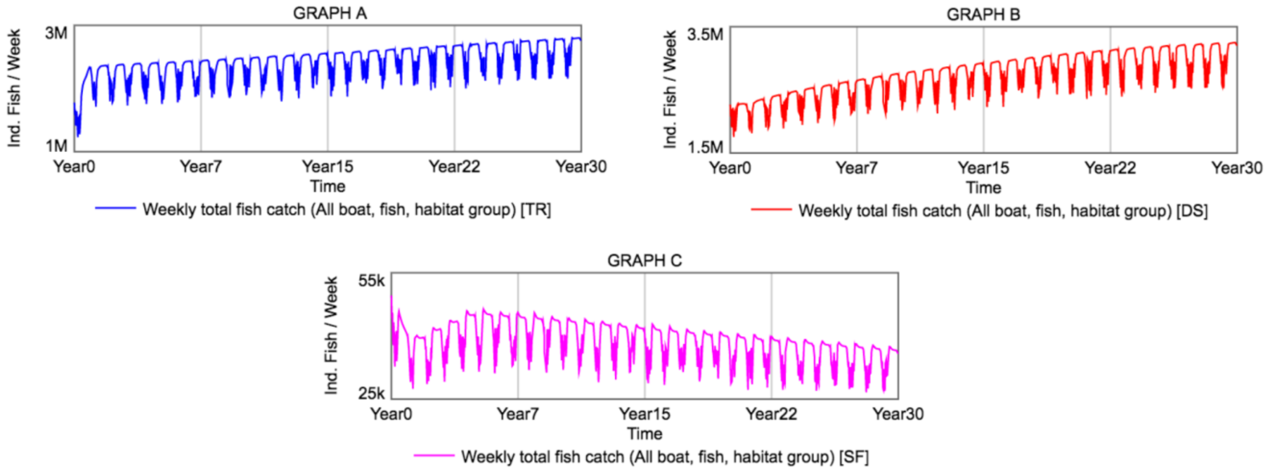


Figure 6-17. Weekly total fish catch from the traditional (graph A), destructive (graph B), and squid/pelagic (graph C) fishing boats of all boat, fish, and habitat categories.

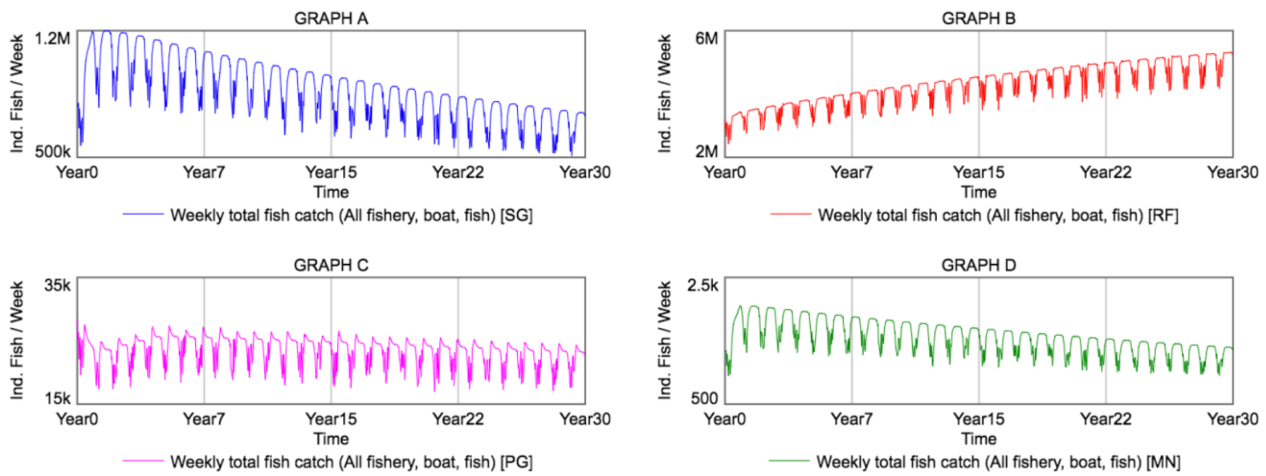


Figure 6-18. Weekly total fish catch from the seagrass (graph A), coral reef (graph B), pelagic (graph C), and mangrove (graph D) habitats of all fishery, boat, and fish categories.

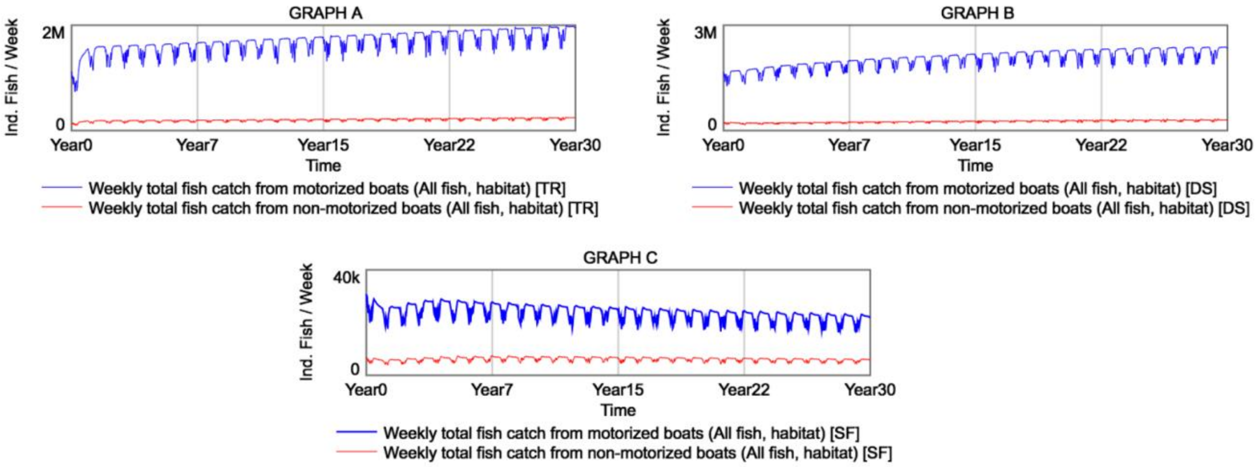


Figure 6-19. Weekly total fish catch from all motorised boats and all non/smaller-motorised boats in the traditional (graph A), destructive (graph B), and squid/pelagic (graph C) fishery groups; of all fish and habitat categories.

6.4.2.4 Local fishing activity / Fishing activity of households

Referring to Figure 6-20, the number of traditional fishers and fishing boats is projected to decline steadily (Graphs A and C, respectively). However, the average fishing hours spent by the boats is gradually increasing (graph B) with most of the fishing efforts increasingly being spent on reef habitat, followed by seagrass with the opposite trend (graph C). From a whole-fishery perspective, the fisher and boat trends are consistent with the desired gradual reduction of fishing activity in the future. However, at the level of individual fisher, as the effort trend is in agreement with the estimated trend of the gradual increase of fishing activity.

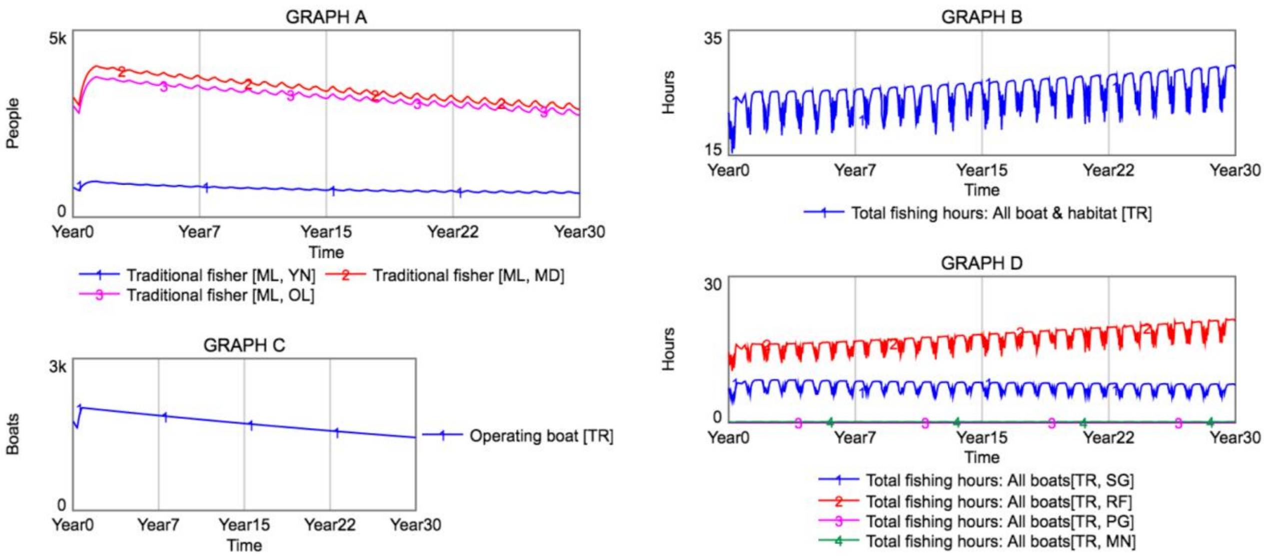


Figure 6-20. The number of traditional fishers (graph A), fishing boats (graph C) and the total average hours spent on fishing per week for all boats and fishing ground (graph B) and of all boats in each fishing ground (graph D).

Trends similar to that of the traditional group are also expected for the destructive and squid/pelagic fisher groups (Figure 6-21 and Figure 6-22 respectively). However, the squid/pelagic fisher group will maintain a yet lower average weekly fishing hours (Graph B, Figure 6-22) compared to the other two fisher groups and concentrate its fishing hours mostly in the pelagic area (Graph D of Figure 6-20 and Figure 6-21). This is also due to the negative effect of the average fishing revenue of squid/pelagic fishers/households, which is also lower than that of the other two groups (Figure 6-37), and therefore suppresses the group's overall effort.

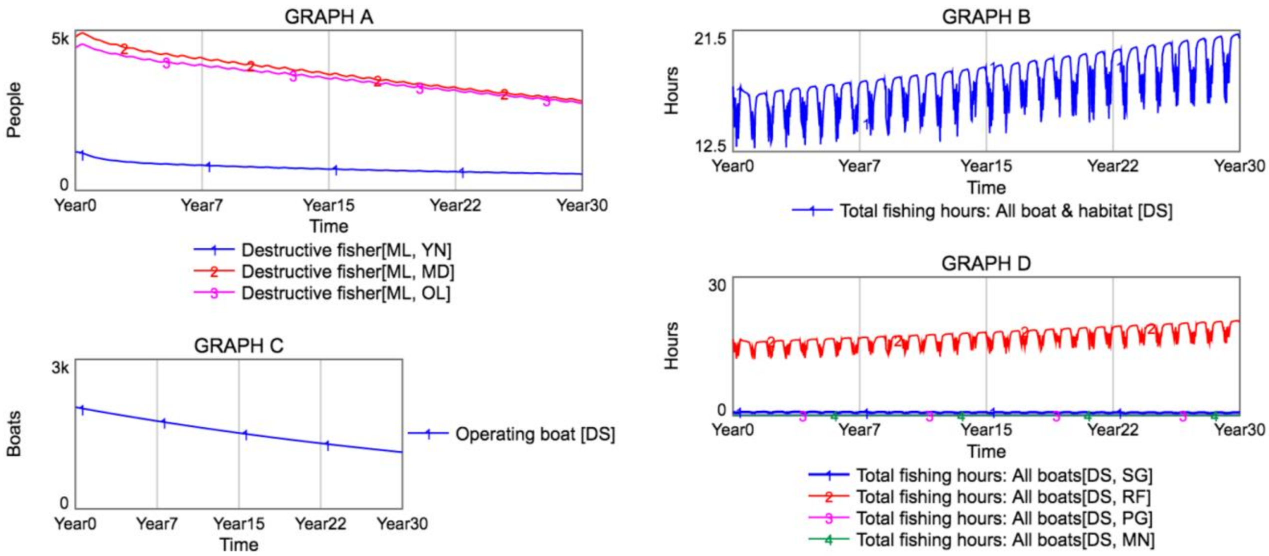


Figure 6-21. The number of destructive fishers (graph A), fishing boats (graph C) and the total average hours spent for fishing per week of all boats and fishing ground (graph B) and of all boats in each fishing ground (graph D).

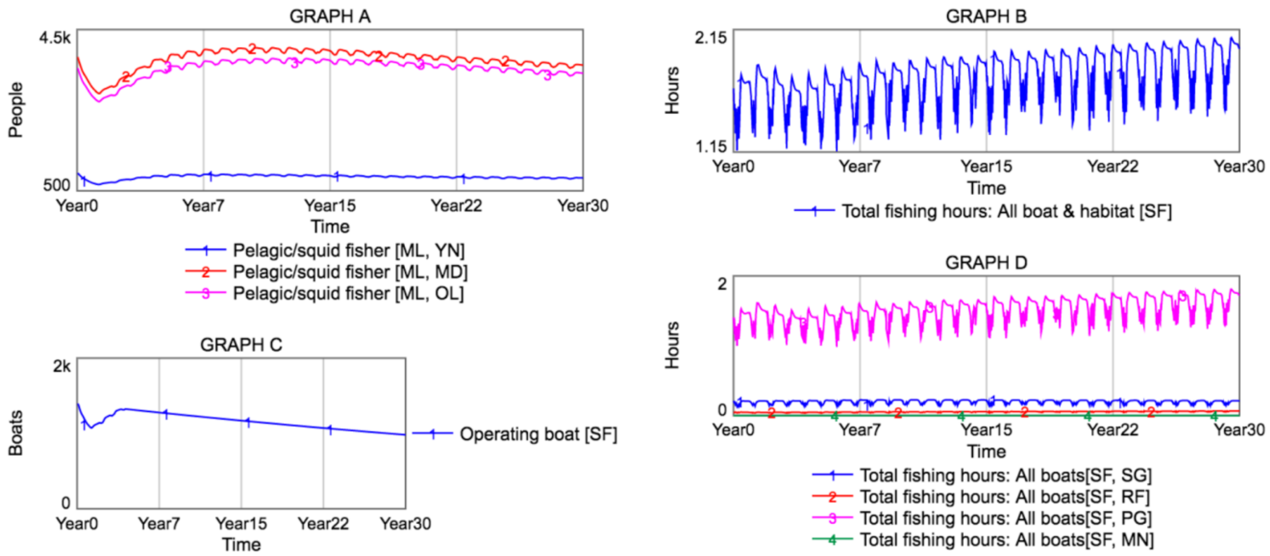


Figure 6-22. The number of squid/pelagic fishers (graph A), fishing boats (graph C); and the total average hours spent for fishing per week of all boats and fishing ground (graph B) and of all boats in each fishing ground (graph D).

Furthermore, the difference in the average fishing profit between each of the fisher groups will maintain a total rate of fisher movement that predominantly shifts fishers from the squid/pelagic fishery to the traditional and at a lesser rate to the destructive group (positive rates in Graph A, negative rates in Graph B, Figure 6-23). This explains the number of squid/pelagic fishers, which would be kept slightly lower than the other two groups over time.

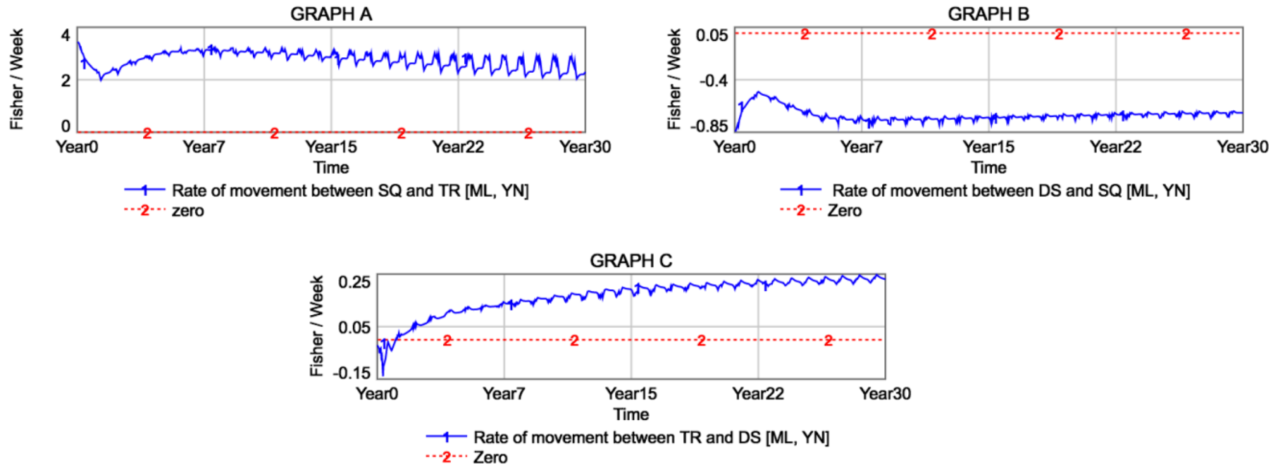


Figure 6-23. The weekly rate of movement of fishers between squid/pelagic (negative value) and traditional (positive value) in graph A, between destructive (negative value) and squid/pelagic (positive value) in graph B, and between traditional (negative value) and destructive (positive value) in graph A. The movement is influenced by the ratio of average fishing profit between one fishery group to another.

In all fisheries, the annual dips in the average weekly fishing hours trends reflect the annual reduction due to the effect of weather disturbance period as depicted in Figure 6-24.

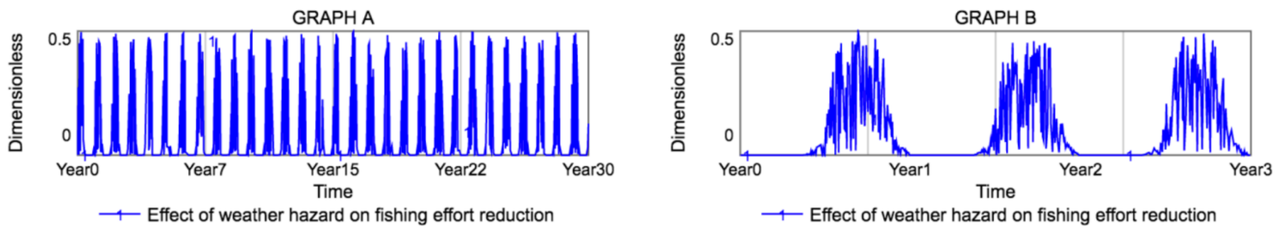


Figure 6-24. Fractional effect of weather disturbance on the reduction on the average weekly hours of fishing, which are randomly generated between a fixed fraction range of 0 to 0.5 with the time horizon (graph A). The effect is applied and diminished gradually within the simulated wet season period (3-year time span scale, Graph B).

6.4.2.5 Trends in human population size

Referring to Figure 6-25, the total human population in Selayar is projected to decrease gradually (graph A). This trend is different from the estimated and desired future trend since the *population level* is both estimated and expected to increase incrementally. This projection is anticipated as it is attributable to the rate of births and deaths that was set to be constant over time for the base case. In this assumption, the total rate of birth is expected to be kept lower than the total rate of deaths for the males (Graph C) and the opposite condition is true for the female rates (Graph D). Consequently, as displayed in Graph B, the trend differs between the gender groups, whereby the total male population is estimated to increase slowly while the opposite trend is experienced by the female population. However, in real life, birth and death rates are dynamic as it is internally and exogenously influenced by multiple factors (e.g,. psychological, cultural, health, and financial).

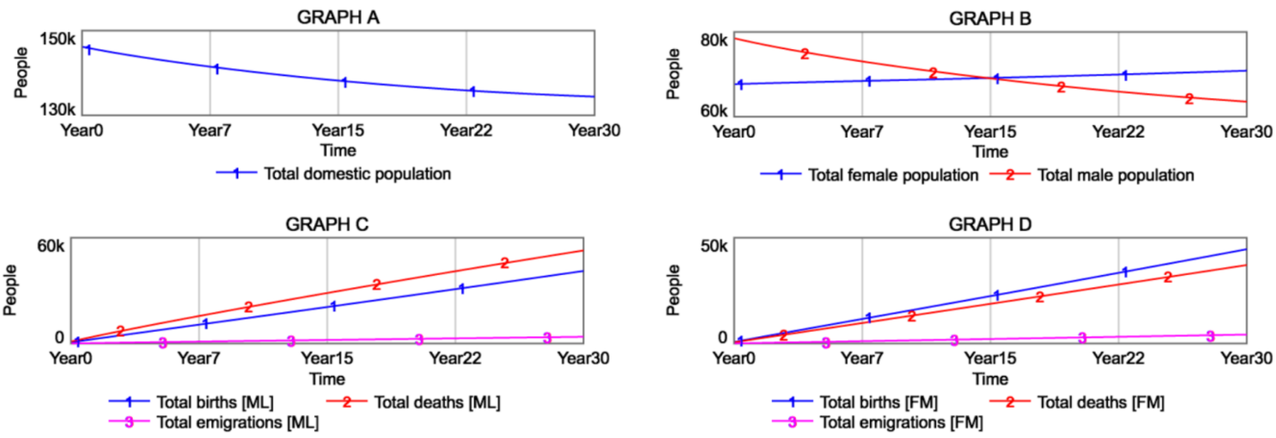


Figure 6-25. Total domestic population of Selayar and Gusung Pasi Island of all sex and age group (Graph A) and by sex group (Graph B). The total births, deaths and emigration of the male (Graph C) and female (Graph D) populations.

Furthermore, from Figure 6-26, we can see that the total number of fishers and non-fishers in the working-age population (Graphs A, B, respectively), and fishers in the traditional, destructive, and squid fishery groups (graph C, D, E, respectively) follow a similar trend to that of the total population. Looking at the labour movement into and out of fisher, the rate of fisher entry and exits are following the same pattern and higher exit rate over time (Figure 6-27. This result is expected, given that the base case excludes factors that can increase labour exiting fishery, such as higher profit of non-fishing work, surveillance, and emigration due to higher financial capacity for tertiary education.

However, due to the difference in the profitability of the three fishing groups (Section 6.4.2.9), squid/pelagic fishing group becomes less favourable. As depicted in Figure 6-28, this is due to the weekly proportion of fishers that are moving out from the squid/pelagic fishery to other fishery group is estimated to be higher than the other groups. The same applies for the fish and habitat condition: the base case for the fisher population is an ideal condition, considering that stabilising or gradual decline of fisher demography is the desired future.

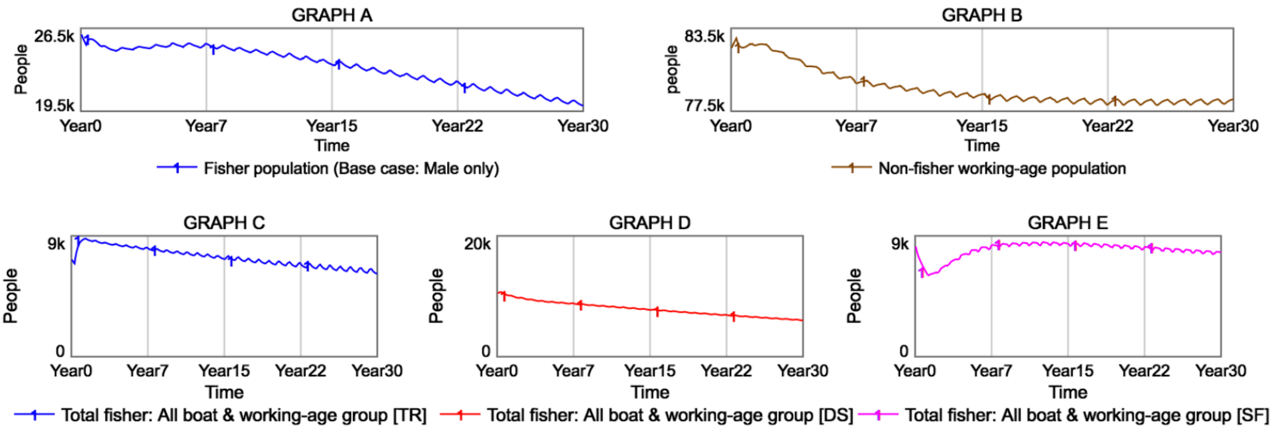


Figure 6-26. Total fisher population (male only) of all fisheries and age groups (graph A). Total non-fishing working-age population (Graph B). Total fishers in the traditional (Graph C), destructive (Graph D), and squid/pelagic groups (Graph E).

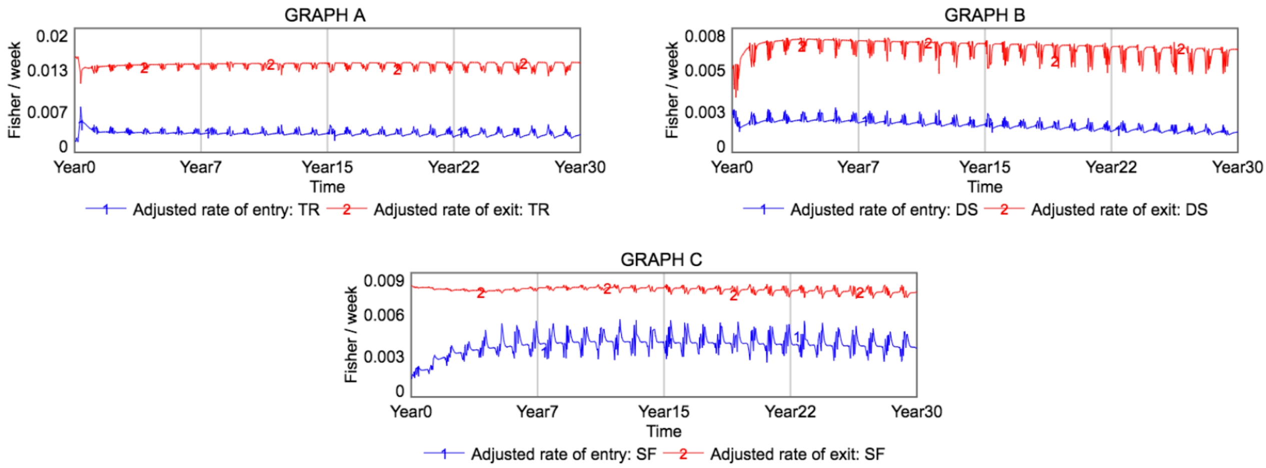


Figure 6-27. The average rate of fisher entry and exit.

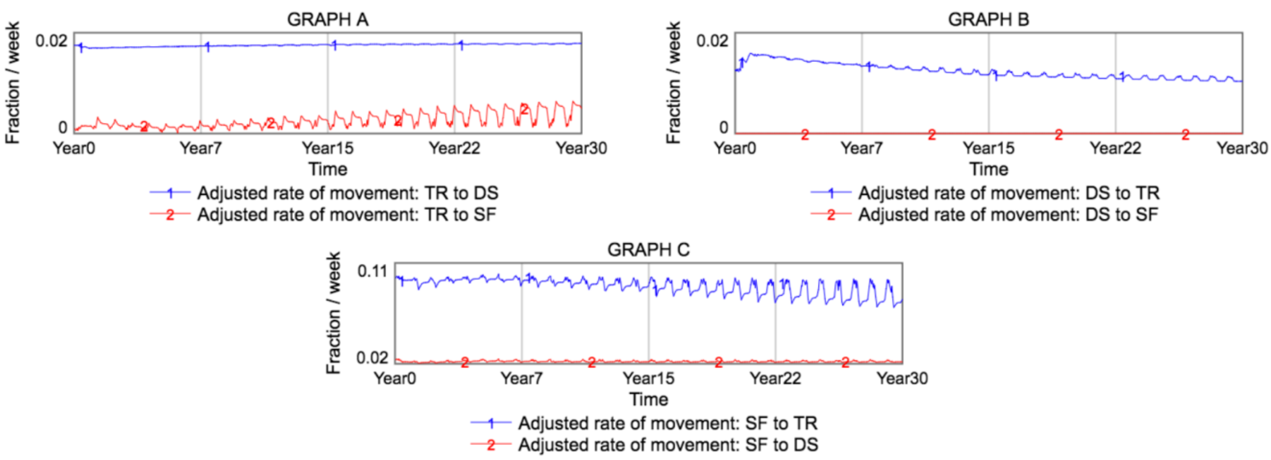


Figure 6-28. The average rate of fisher movement between fishery groups.

6.4.2.6 Fish price (including fish supply and demand)

As seen in Figure 6-29, for all fish groups (in Graphs A, B, and C), the domestic price of fish is likely to decline steadily with annual spurs of price increase occurring during the months of disrupted fishing that trigger a lower ratio of supply to demand (Figure 6-31). The reason for this trend is that, for the base case, the positive influence on price dynamics solely from the fish consumption of the non-fishing households. Consequently, the trend if fish follows the gradual decline of the non-fisher working age population. In general, the price trend differs from both the estimated and the desired gradual increase in fish price. Yet, the projected price decline supports the finding of the restricted marketing (i.e., oligopsony) of the fish catch landed locally to the island (i.e., domestic supply). Consistent with this, the total volume of unsold fish on the island is projected to increase steadily (Figure 6-30).

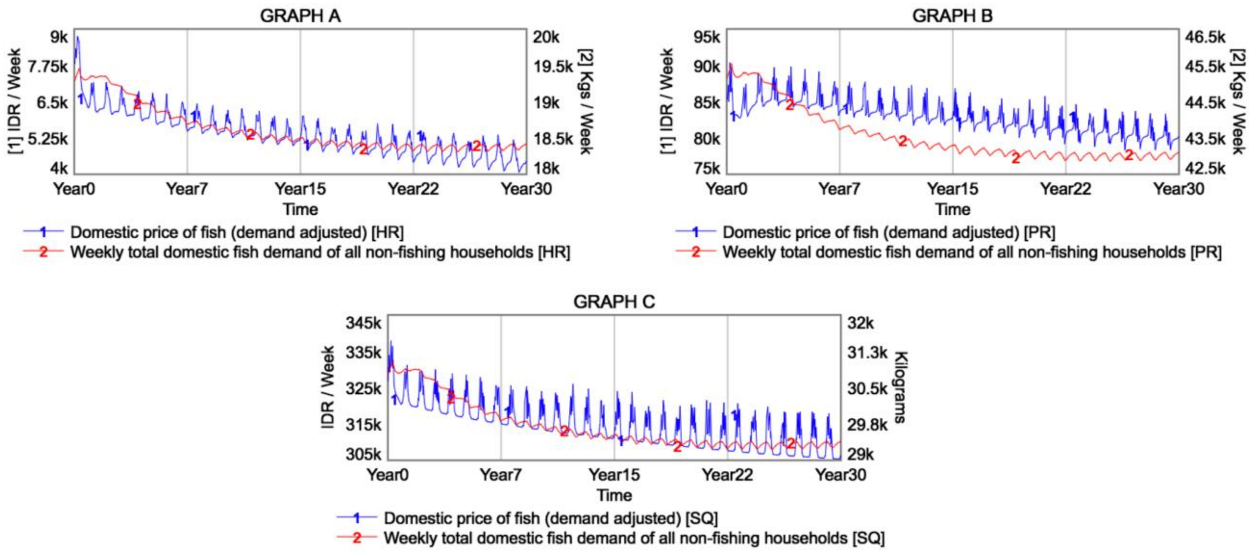


Figure 6-29. Domestic price of fish and weekly total domestic fish demand from all non-fishing households; each for the herbivorous, predatory, and squid/fast-reproducing fish group (Graphs A, B, and C, respectively).

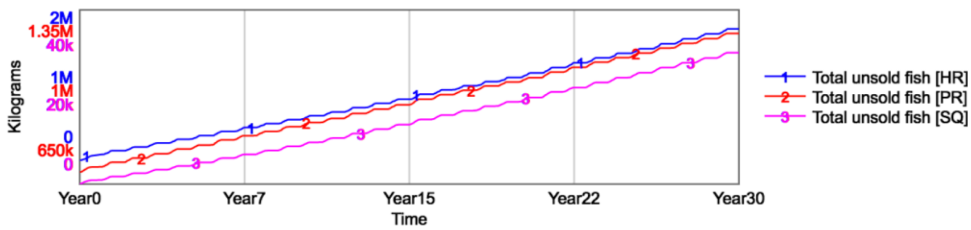


Figure 6-30. Total volume of unsold fish landed on the island over time, for each of the fish categories.

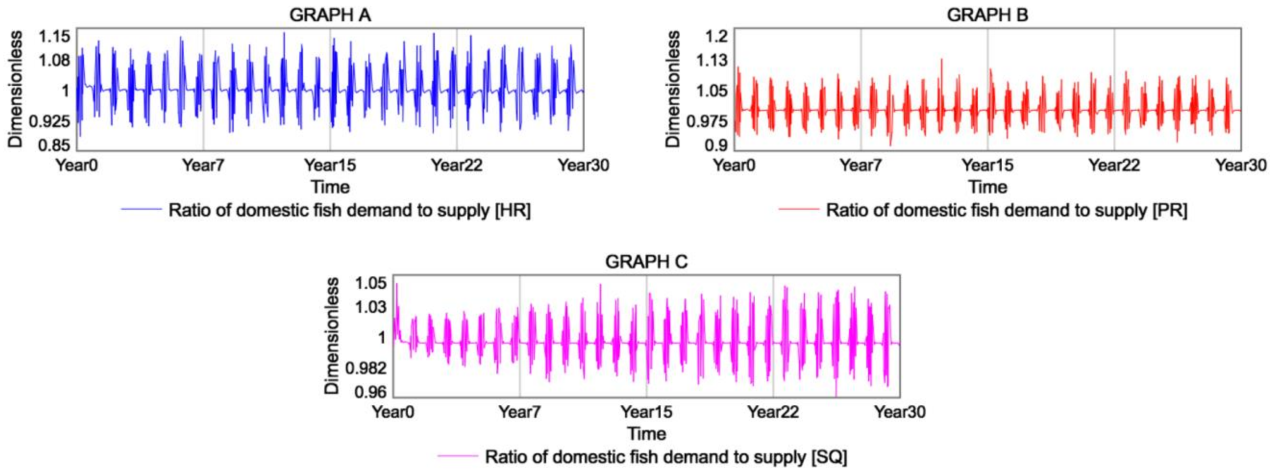


Figure 6-31. The ratio of domestic fish demand to fish supply for the herbivorous, predatory, and squid/fast-reproducing fish groups (Graphs A, B, and C, respectively).

Despite the undesirable estimation of domestic fish price dynamics, as seen in Figure 6-32, the base case model generously ensures that the weekly fish sales for export (i.e., for consumption outside the island) are maintained over time under a fixed export fish price of triple the value in Year 0 (2016).

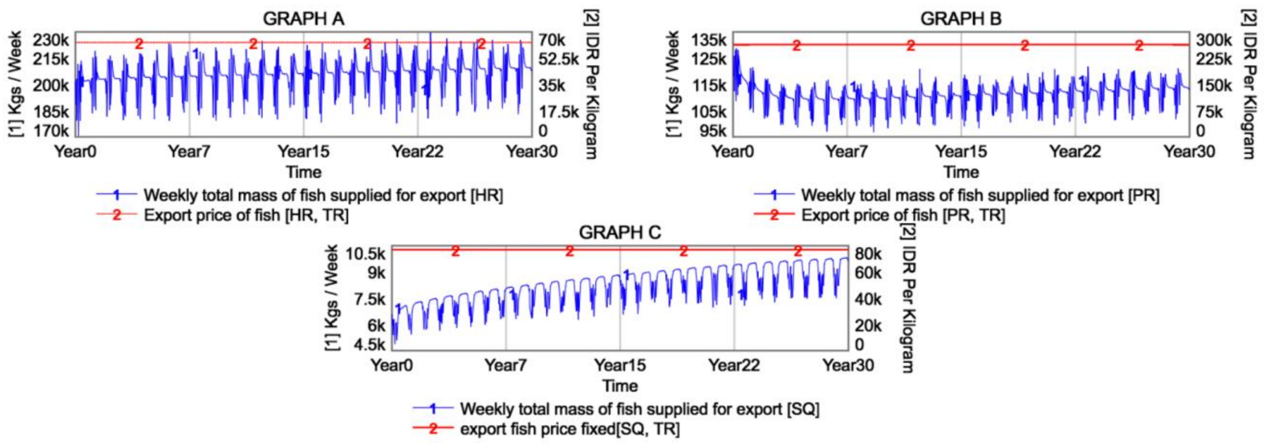


Figure 6-32. Weekly total of fish supplied for non-domestic market and the fixed export price of fish, each for the herbivorous, predatory, and squid/fast-reproducing fish group (Graphs A, B, and C, respectively).

6.4.2.7 The financial burden of households: The ideal, expected, and fulfilled costs of living

Figure 6-33 shows that the ideal average weekly cost of living for all six household categories increases over time. However, households are expected to be driven to maintain a lower expected weekly cost of living. These reductions in the living standards are associated with reoccurring weekly episodes of deficits as well as costs of loan repayments experienced under all household categories (Section 6.4.2.8) that warrant additional spending of the household savings (i.e., net income). As a result, under the optimistic assumption of a gradual increase of *household need* in the future reflected by the effect of inflation, the fulfilled costs of living are always below the expected state of living for all household categories (Figure 6-34)

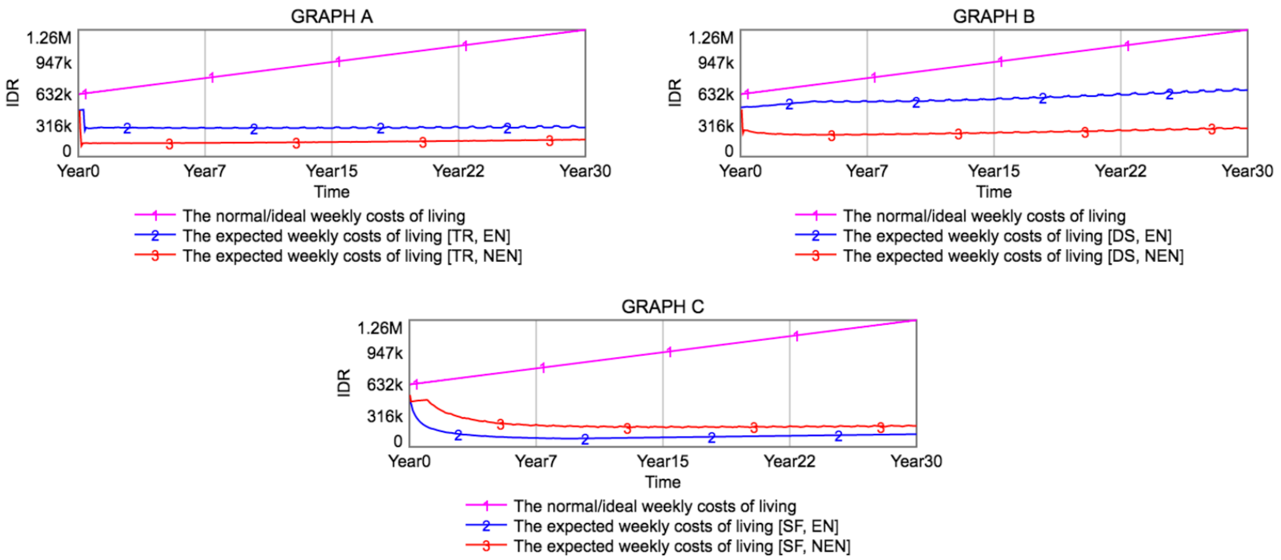


Figure 6-33. The normal (ideal) and the expected average weekly costs of living of the households predominantly engaged in the traditional (Graph A), destructive (Graph B), and squid/pelagic (Graph C) fishery; which either using boats with a larger motor or with smaller/no motor.

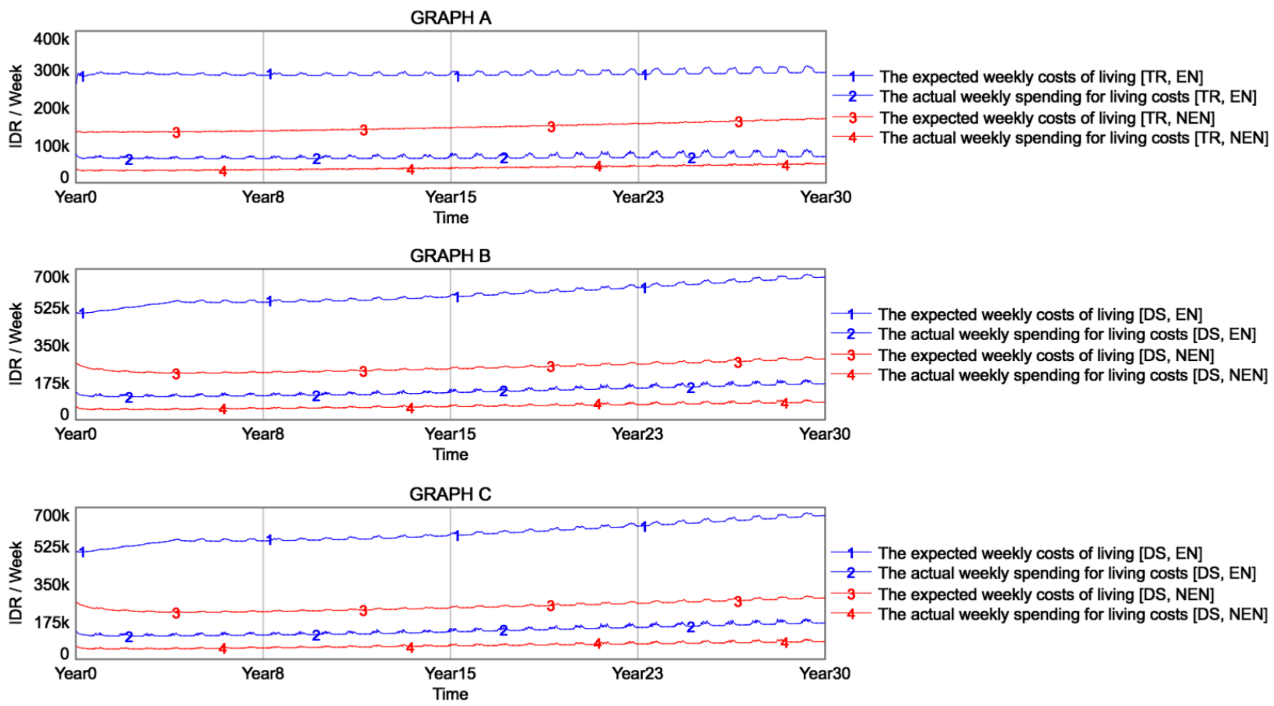


Figure 6-34. The expected and actual average weekly spending for the costs of living of the households predominantly engaged in the traditional (Graph A), destructive (Graph B), and squid/pelagic (Graph C) fishery; of each that either using boats with larger motor or with smaller/no motor.

6.4.2.8 The financial burden of households: Deficit and debt

As shown in Figure 6-35, the weekly spending for offsetting deficit is also maintained over time for all household categories (Graphs A, B, and C) at a level that is, however, unable to fully resolve deficit (Graphs D, E, and F). Accordingly, since the model sets cash loan as the last option of financial support, most of the weekly money lending episode is intended to cover both current and last week’s deficit. As a result, as shown in Figure 6-36, the weekly spending on loan repayment purpose of all six fishing household categories is projected to be maintained and increased over time (Graphs A, B, and C), which is consistent with the increased of the average total debt of each household (Graphs D, E, and F). Although there were no records of the perceived trend for debt, the projections reflect the erosion of household capacity to cope with a financial crisis due to the accumulation of debt (Graphs D, E, and F).

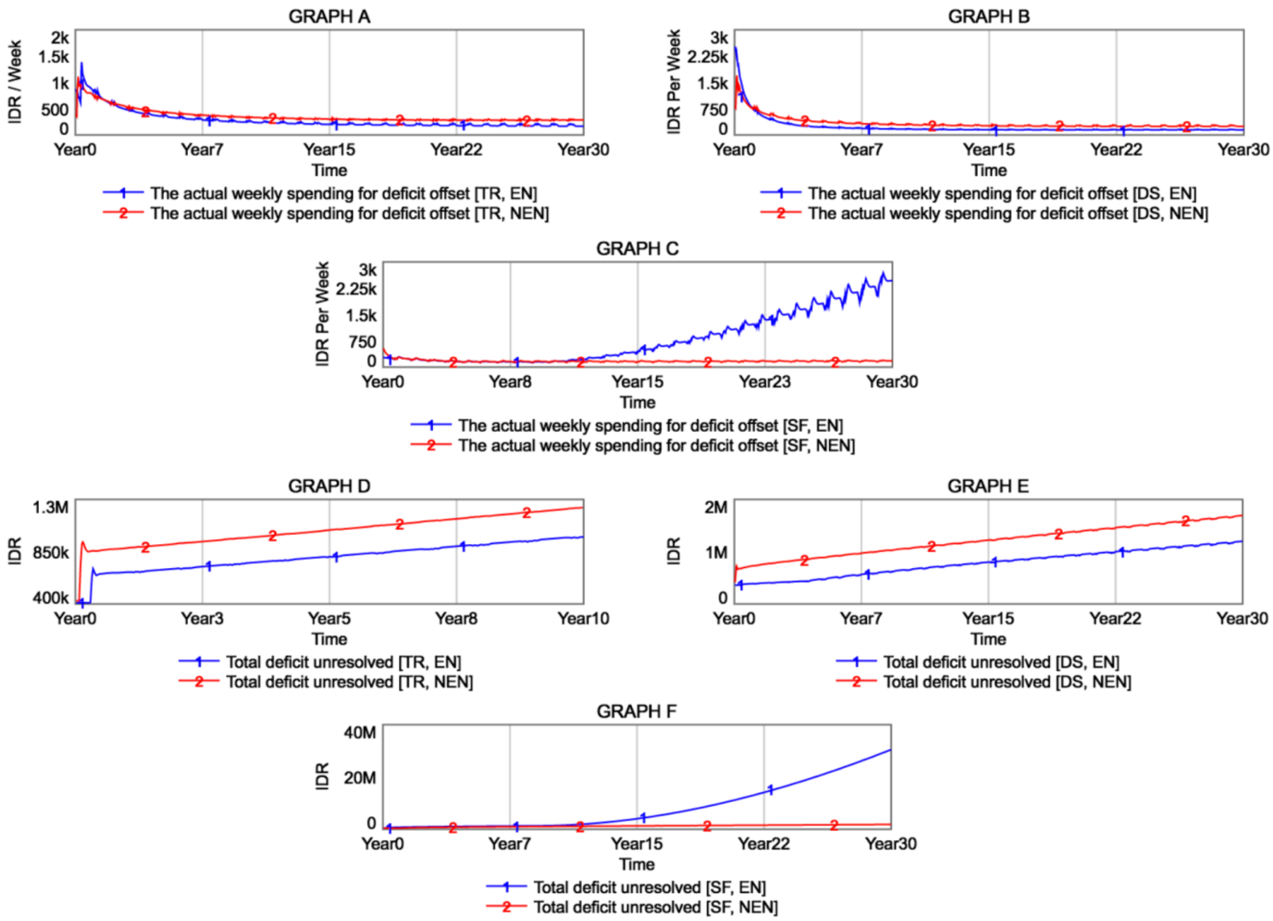


Figure 6-35. The average weekly spending for the offset of deficit in the current week (top three graphs), and the average unresolved deficit (bottom three graphs) of the households predominantly engaged in the traditional (Graphs A & D), destructive (Graphs B & E), and squid/pelagic (Graphs C & F) fisheries of each that either using boats with larger motor, or with a smaller or no motor .

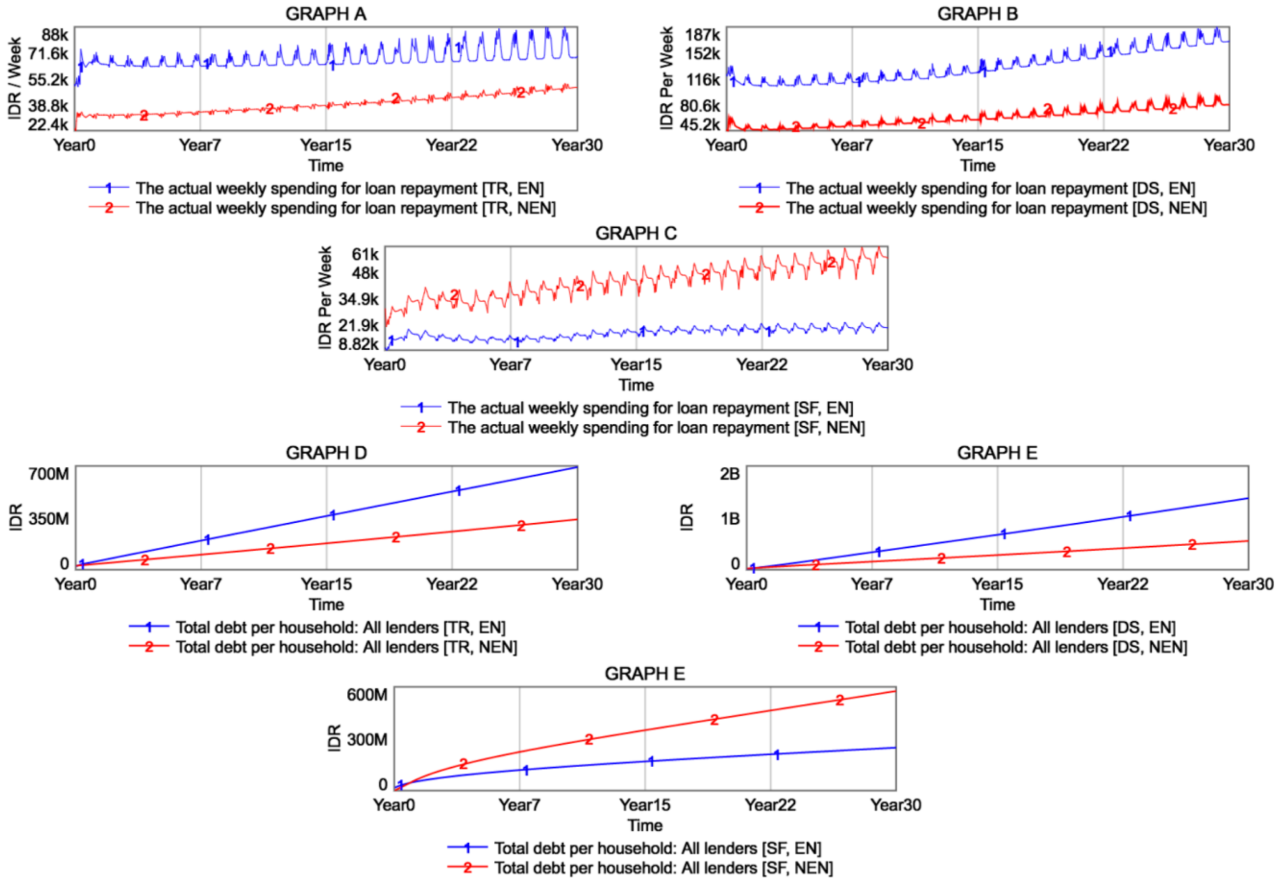


Figure 6-36. The average weekly spending for the fulfilment of loan repayment costs and the average total debt of the households predominantly engaged in the traditional (Graphs A & D), destructive (Graphs B & E), and squid/pelagic (Graphs C & F) fisheries, of each that either using boats with larger motor, or with a smaller or no motor.

6.4.2.9 Total household income (Profit of fishing)

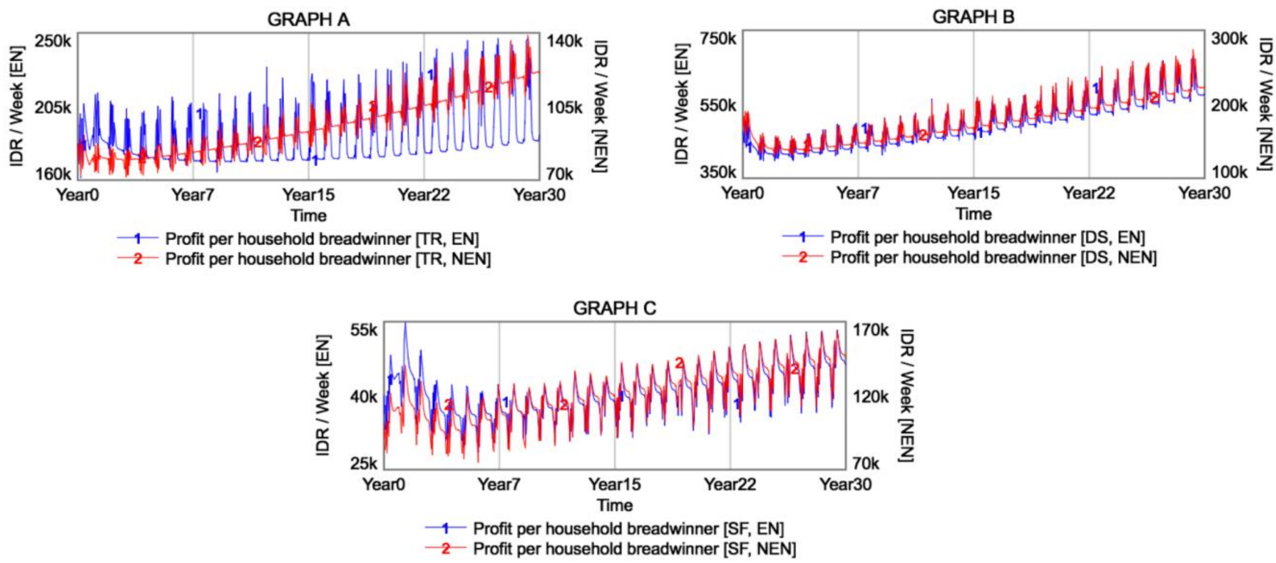


Figure 6-37. Average weekly profit earned by the fishing breadwinner of the households predominantly engaged in the traditional (Graph A), destructive (Graph B), and squid/pelagic (Graph C) fishery, of each that either using boats with larger motor, or with smaller/no motor.

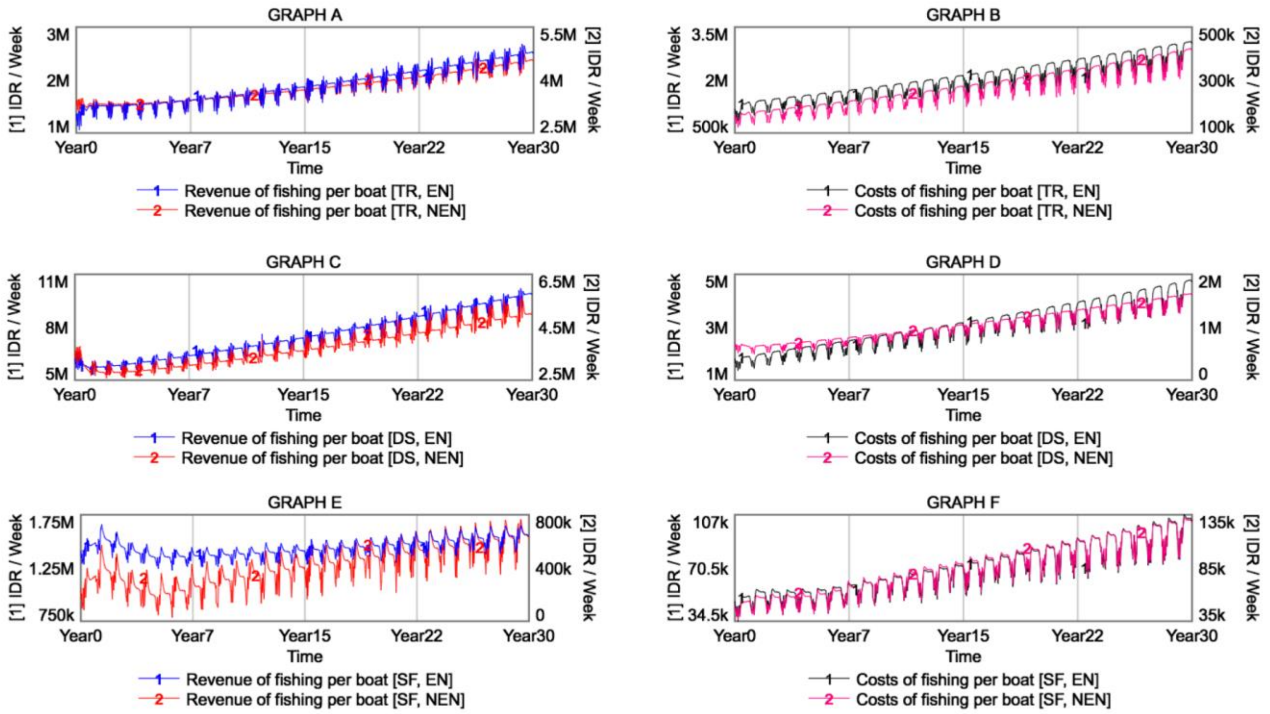


Figure 6-38. Average weekly revenue (left side) and costs of fishing operation (right side) of the fishing boats of the households predominantly engaged in the traditional (Graph A & B), destructive (Graphs C & D), and squid/pelagic (Graph E & F) fisheries,, of each that either using boats with larger motor, or with a smaller or no motor .

6.4.2.10 Household savings: Weekly income stream, net income, and disposable income allocated for costs of supplementary work and of emigration (e.g., tertiary education)

As depicted in Figure 6-39, under the base case scenario of income sourced only from fishing, the average weekly income addition of all household categories is projected to increase slowly. This trend reaches a final level which, however, is not significantly higher than the initial rate. A modest difference is displayed from the traditional fishers with a larger engine, which involves a steady increase only of the maximum the income rate during the weather disruption period (Graph A). This, however, involves a relatively unchanging rate in the normal weather period (Graph A). Over time, the lowest rate of income is established for the squid/pelagic households (Graph C) and is not expected to surpass the other groups over time. Although the total revenue of all larger engine boats is generally higher than the smaller/non-engine boats, for squid/pelagic households, the average weekly income of the larger engine boats is rendered lower as the number of boats operating – the denominator – is higher than smaller/non-engine boats. Other than the latter two differences, the overall trends are consistent to that of the estimated as well as the desired by the fishers, which, however, maintained a level that is undesirably below the ideal average costs of living.

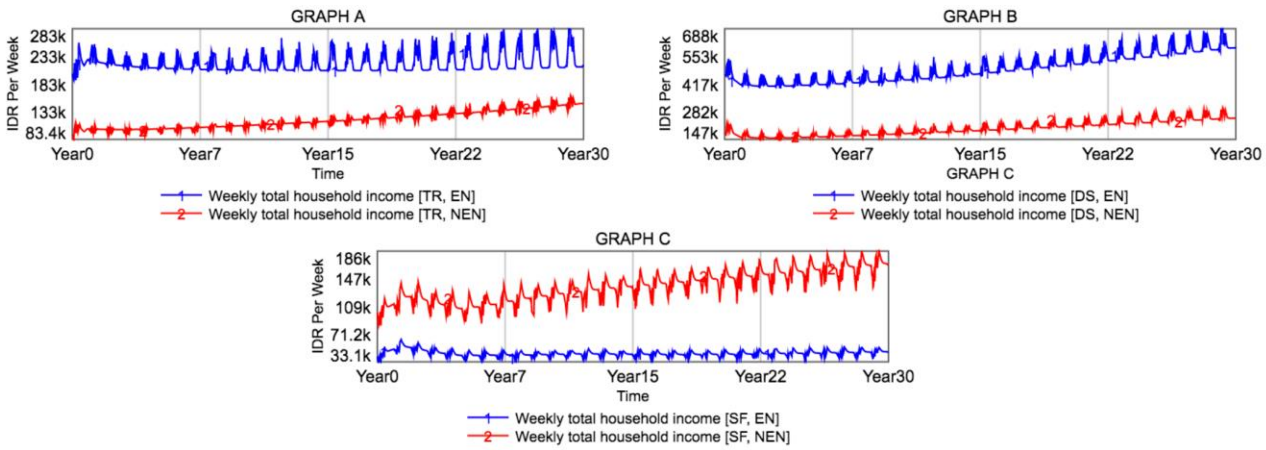


Figure 6-39. The average weekly total income stream of the households predominantly engaged in the traditional (Graph A), destructive (Graph B), and squid/pelagic (Graph C) fisheries; of each that either using boats with larger motor, or with smaller/no motor.

Parallel to this, as portrayed in Figure 6-40, the average cash savings of all household categories is likely to increase moderately with a maintained level similar to the weekly income stream. Under the scenario of a single source of income, the base case model projects a zero average weekly spending for the operational costs of non-fishing work for all household categories (Figure 6-41). In this condition, other than squid/pelagic using smaller boats, most households will maintain a gradual increase of the weekly disposable income that is, however, at a level lower than the weekly required costs of tertiary education that projected to rise steadily over time (Figure 6-42).

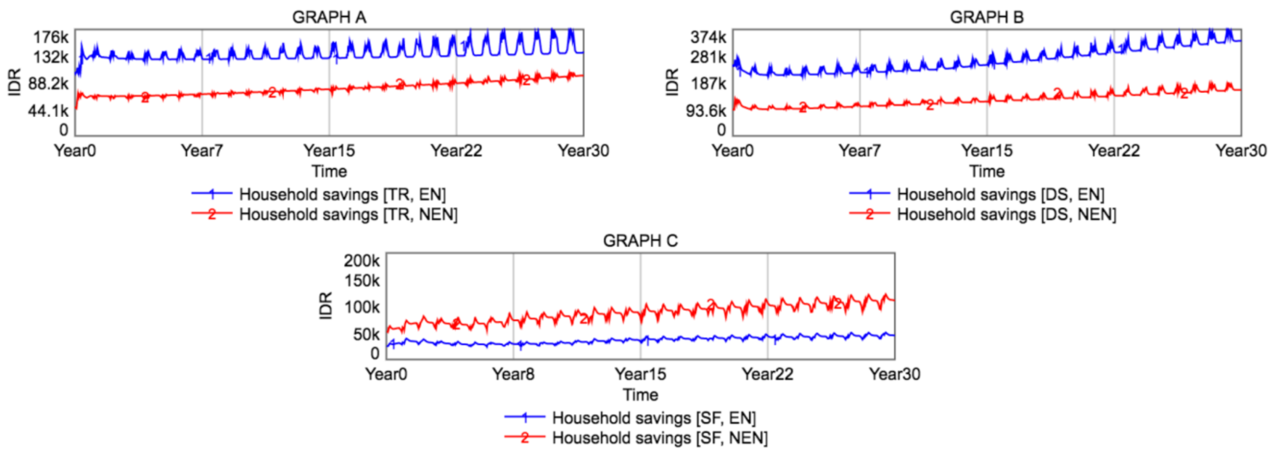


Figure 6-40. The average weekly total savings (i.e., net income) of the households predominantly engaged in the traditional (Graph A), destructive (Graph B), and squid/pelagic (Graph C) fisheries, of each that either using boats with larger motor, or with smaller/no motor.

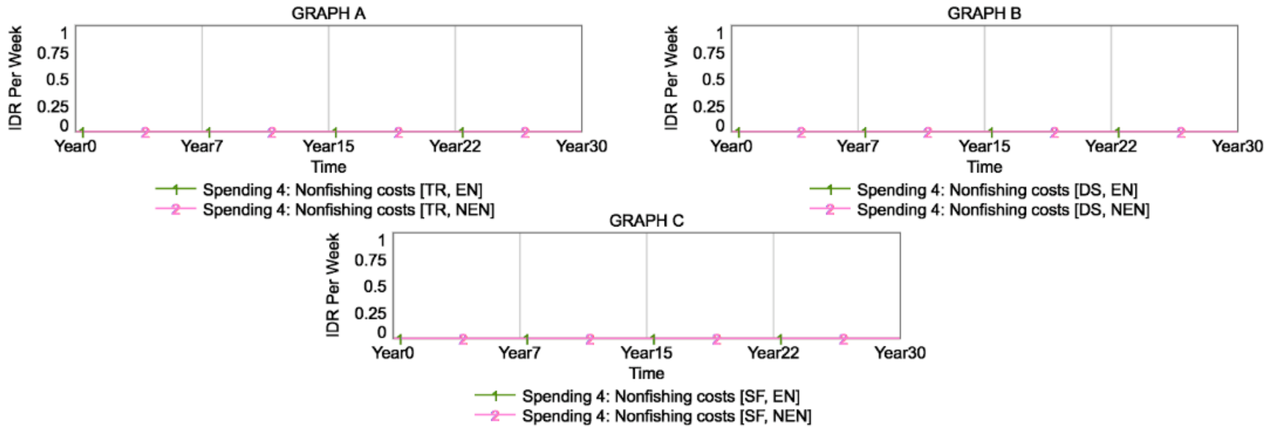


Figure 6-41. The average weekly spending for the costs of non-fishing work of the households predominantly engaged in the traditional (Graph A), destructive (Graph B), and squid/pelagic (Graph C) fisheries, of each that either using boats with larger motor, or with smaller/no motor.

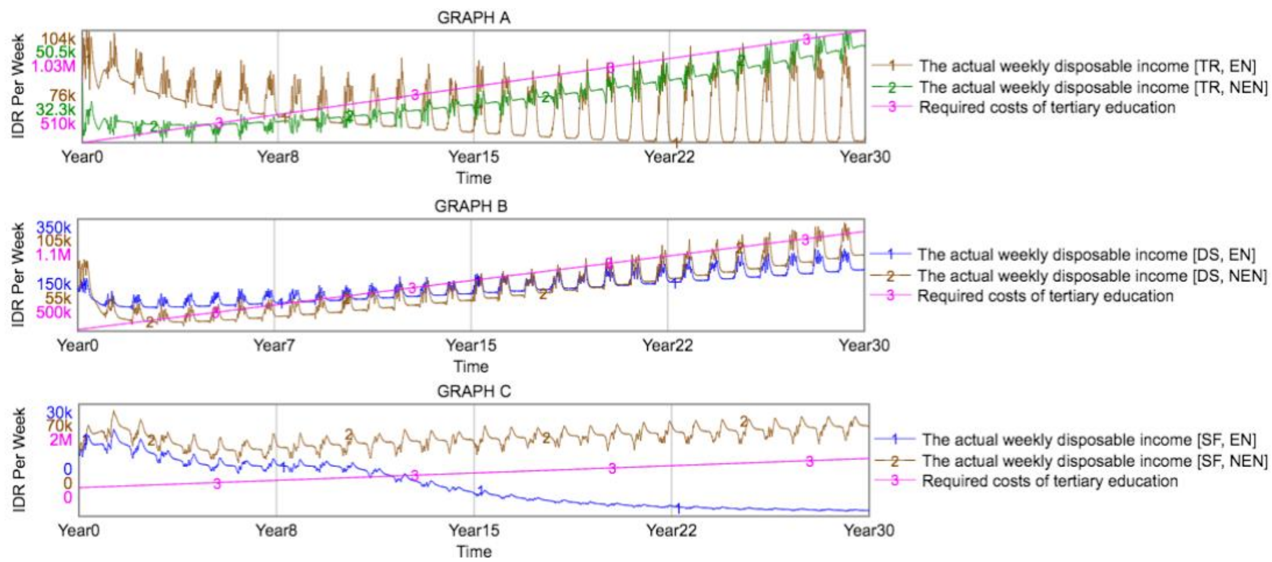


Figure 6-42. The weekly average of disposable income of the households predominantly engaged in the traditional (Graph A), destructive (Graph B), and squid/pelagic (Graph C) fisheries, of each that either using boats with larger motor or smaller/without motor; and the required average of weekly costs of tertiary education.

Under the state of disposable income, no households will be able to finance the costs of at least a week of tertiary education outside the island (Figure 6-43). Overall, the disposable income will therefore be reallocated to household savings (Figure 6-44) as a strategy to cope with the deficit and debt burden.

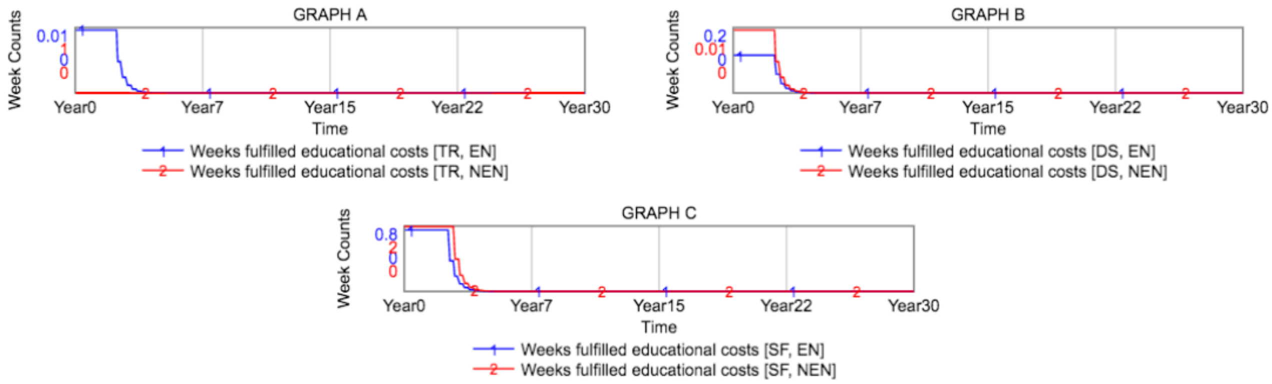


Figure 6-43. The average weeks of maintained financing for tertiary education by the households predominantly engaged in the traditional (Graph A), destructive (Graph B), and squid/pelagic (Graph C) fisheries, of each that either using boats with larger motor or smaller/without motor; and the required average of weekly costs of tertiary education.

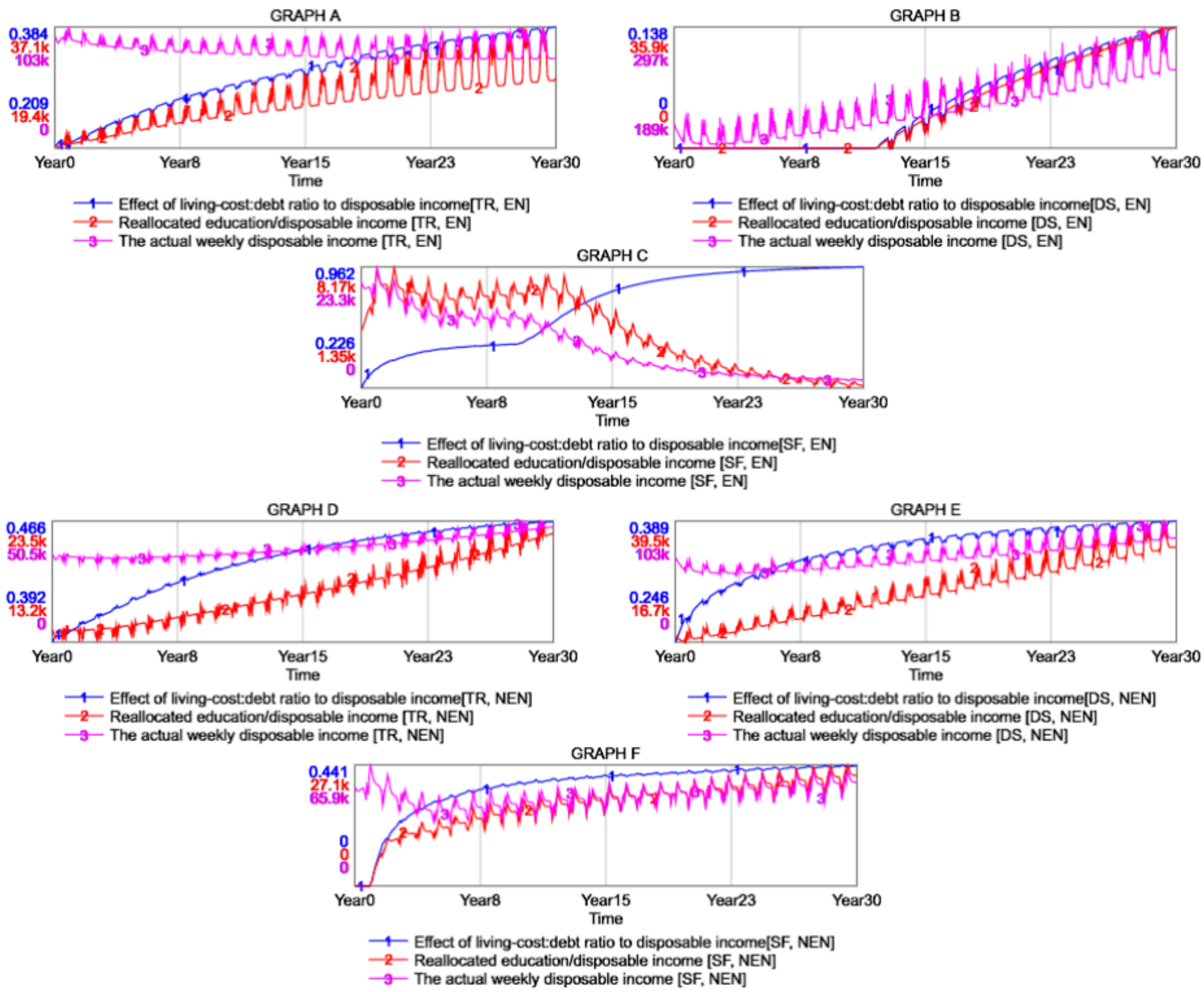


Figure 6-44. The average weekly disposable income reallocated back to savings by the households predominantly engaged in the traditional (Graphs A,D), destructive (Graphs B,E), and squid/pelagic (Graphs C, F) fisheries.

6.5 Result 5: Impact of external fishing on the system behaviours using the 'alternative base case' model

Continuing the model explanation in Section 6.1.2.21, an additional structure was added to the base case model to simulate the impact of *fishing activity by non-Selayar fishers* to the Selayar small-scale fishery system (i.e., base case). The model will from now on be referred to as the 'alternative base case' (ABC).

The ABC model was not used as the working model to test policies unlike the base case model (in Chapter 7). Instead, the model use was limited to assessing system behaviour reproduction under the scenario of the exogenous influence of *fishing activity by non-Selayar fishers, which* was due to the parameterisation of the influence that was based ad hoc hypothesis (see next section). Some of the reasons are that, at the time of the study, the team did not identify any of the FGD and interview participants that have been/were involved with the external fishing activity. Also, pre-existing information that is specific to the Selayar fisheries was unavailable to aid in, for example, defining and justifying the parameter assumption. Similarly, the pre-existing socio-economic dataset (BioLewie household survey: Section 3.6.6.2) did not include any basic information that can parameterise external fishing activity (e.g., the number of boats operating, the rate of catch, fishing seasons).

6.5.1 Additional model design to simulate the impact of *fishing activity by non-Selayar fisher*

The impact of *fishing activity by non-Selayar fishers* (hereinafter referred to as 'external fishing') was modelled as a rate of fish extraction of the adult fish population in the fishing area of the Selayar fishers. The rate of fish extraction by external fishing was represented using the *external catch abundance* outflow, which was arrayed only by *fish* class in the unit of fish individuals per week. In general, the effect of external fishing was parameterised using a liberal estimation meaning that the actual rate is likely higher in the real world, which assumes that:

1. External fishing comprises of both medium and large-scale fishing vessels (i.e., above ten GT) originating both from and outside of Indonesia.
2. There is an 'average' rate, which was represented by a fixed value of the rate of extraction by external fishers (individual fish/week) over the simulation period.
3. The rate of extraction by external fishing is equal to the initial (i.e., the year of 2016) weekly rate of extraction by all the fishing boats in Selayar. This assumption rests on the findings of Pauly (2008) in (Jacquet & Pauly 2008) that the annual global fish catch between small-scale fisheries and large scale fisheries is almost equal.

4. External fishing only affects the coral reef and the pelagic habitats (i.e., fishing grounds of the Selayar fishers) assuming that these habitats can extend to mid-shore to offshore areas and, therefore, accessible to external fishers such as purse seine vessels. Based on this assumption and assumption number 3, for example, if the total abundance of the adult predatory fish caught by all Selayar boats in the reef habitat is 1000 fish individual/week, then the rate of extraction by external fishing from the reef habitat is the same. Additionally, if somehow the fish stock of the habitat is lower than the rate of extraction, then the rate value is set as the current fish stock value.
5. The weather hazard also negatively influences external fishing. Therefore, the similar reduction effect of weather hazard to fishing effort (Section 6.4.2.4, Figure 6-24) was also applied. However, the reduction effect was set 50% lower than the value applied to the Selayar fishers, which assumes that the larger vessels used in the external fishing can operate longer during the fishing days in the bad weather seasons.

The additional stock-and-flow structure and the embedded Stella equations that model these assumptions can be found in Appendix 18 (under ‘Sector 3’). As shown in Figure 6-45, several rates of extraction by external fishing were produced using the alternative base case model, which remained relatively stable over time. The rates in the pelagic fishing grounds were lower than those of the reefs, which follows conditional rule number 4.

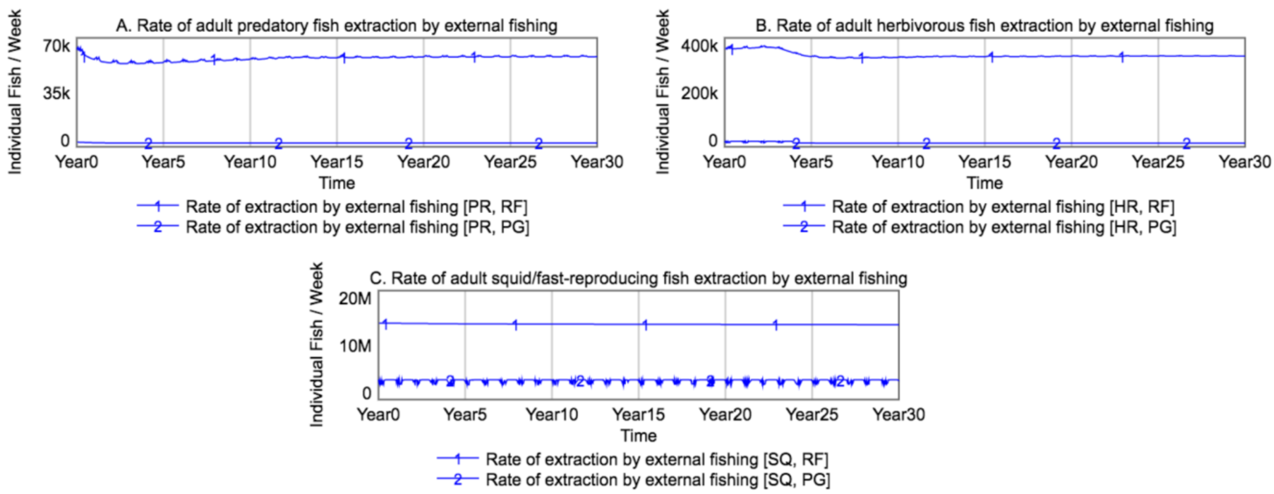
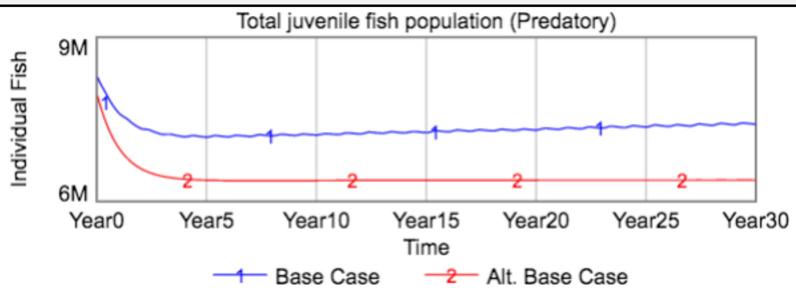
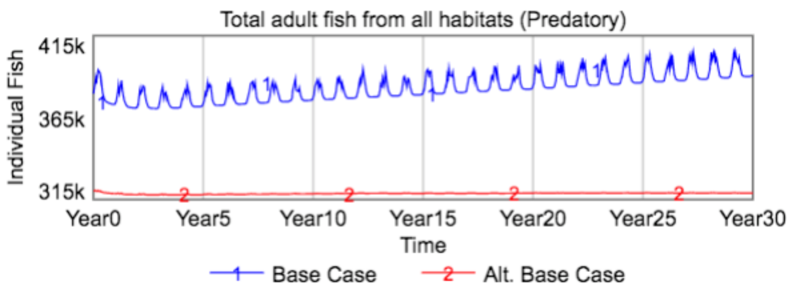


Figure 6-45. The hypothetical average weekly amount of fish extracted by non-Selayar fishing vessels from the predatory (A), herbivorous (B), and squid/fast-reproducing fish populations applied in the alternative base case model. Each graph displays two rates of extraction from the reef (RF) and the pelagic (PG) habitat (fishing grounds).

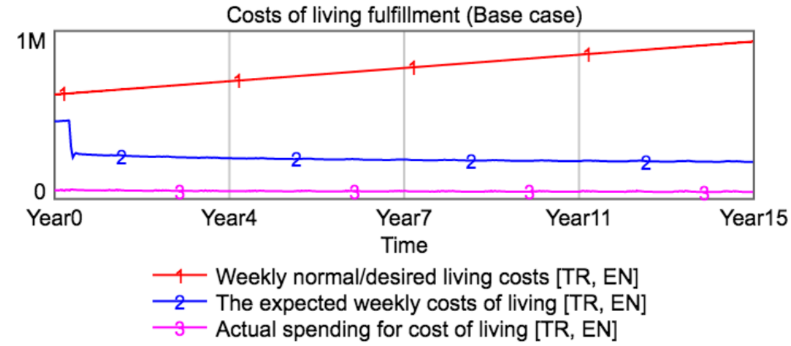
6.5.2 System behaviours produced using the alternative base case model

Overall, under the alternative base case model (ABC model), the additional weekly extraction of adult fish by external fishing would produce problematic system behaviours that define the problem of *declining reef fisheries* similar to those produced under the base case model. However, most of the problematic trends are more undesirable in terms of the equilibrium levels (e.g., lower net income levels) and the speed of change (e.g., higher accumulation of debt). Comparative simulation outputs between the base case and the alternative base case model are presented in Table 6-5 using selected state variables and dimension elements (following Table 6-4).

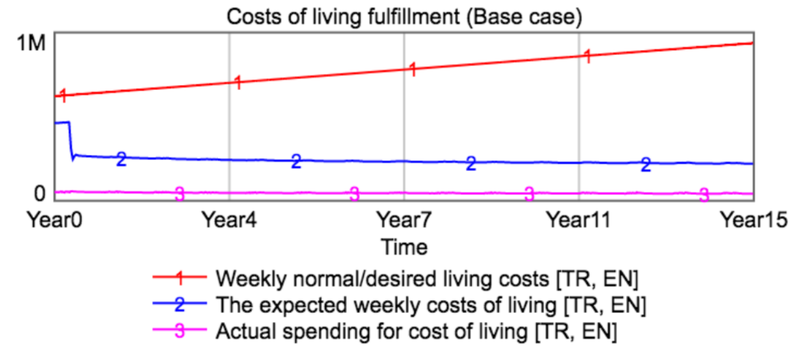
Table 6-5. Comparative line graphs showing output behaviour of the state variables under the base case and the alternative base case (ABC) model (i.e., with and without the impact of external fishing).

No.	Comparative line graphs of the simulation outputs	Behaviour description
1.	 **A.**  **B.**	Both the stock of juvenile (A) and adult (B) fish will be maintained at a lower equilibrium level under the ABC model. Similar behaviour was also produced for the herbivorous and squid/fast-reproducing fish groups (results not presented here).

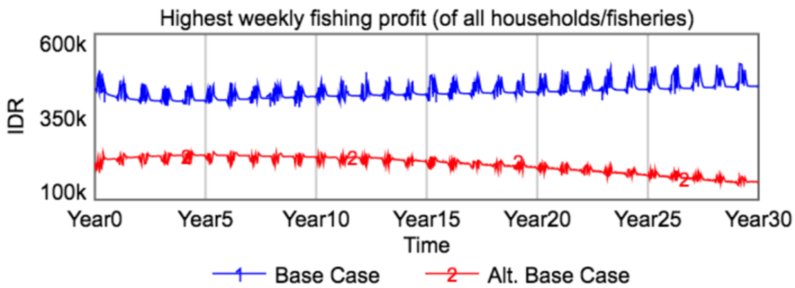
2.



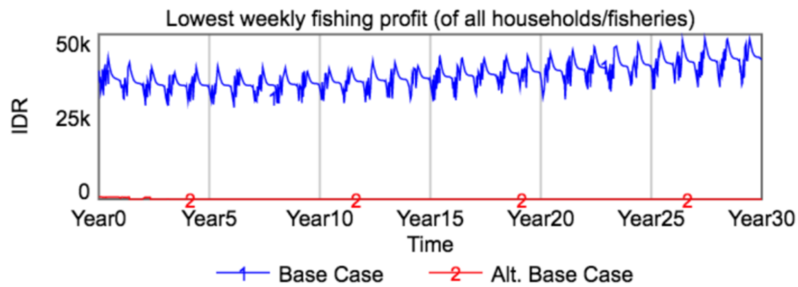
A.



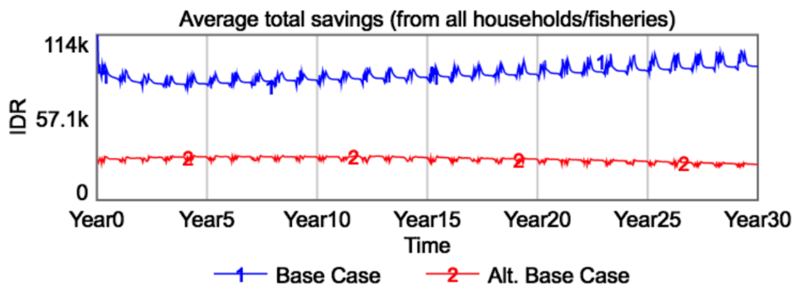
B.



C.



D.

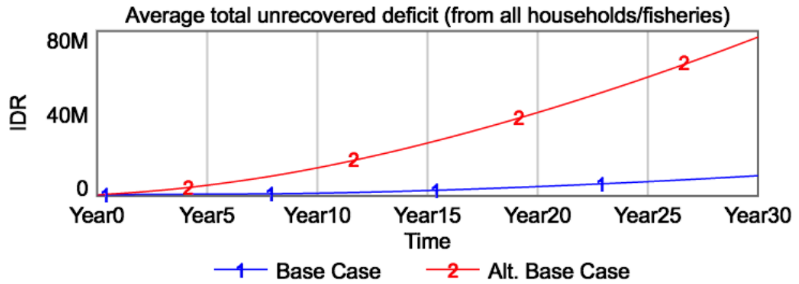


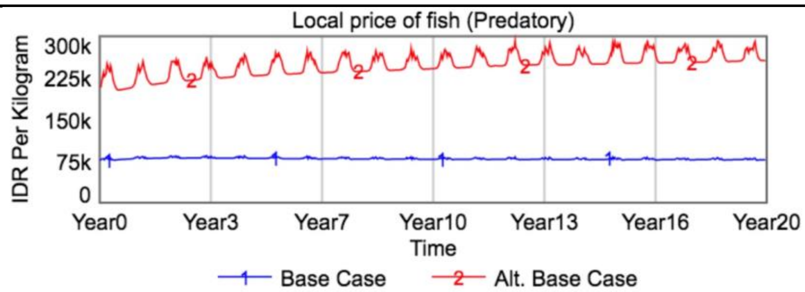
E.

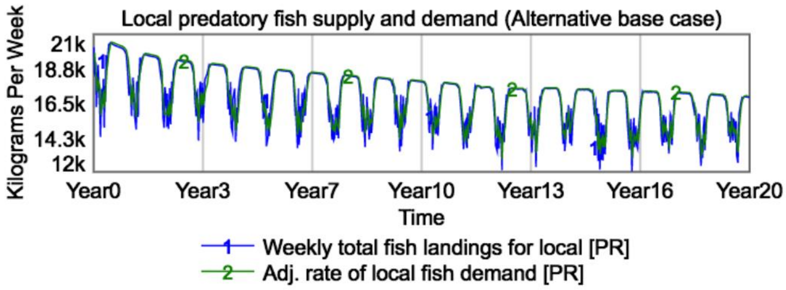
Under a lower fish population level, the budgeted and the actual spending for weekly costs of living will remain below the poverty line under the ABC model (A), which is similar to the base case output (B).

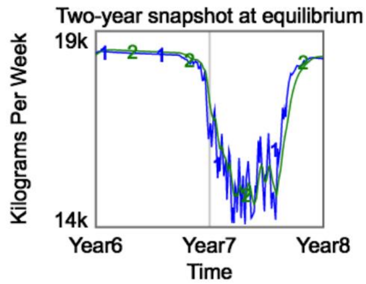
The highest (C) and lowest (D) weekly fishing profit among all of the six fishery groups in Selayar, will be lower under the ABC model.

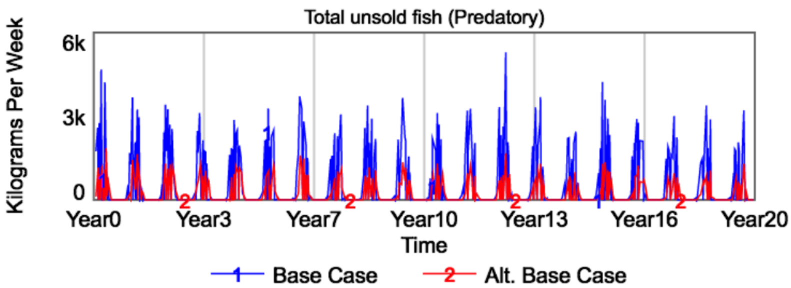
These circumstances will result in lower average net income (savings) of the Selayar fishing households (E), and more episodes of unresolved deficits (F).

<table>
<tr><th>No.</th><th>Comparative line graphs of the simulation outputs</th><th>Behaviour description</th></tr>
<tr><td></td><td>

F.</td><td></td></tr>
<tr><td>3.</td><td>

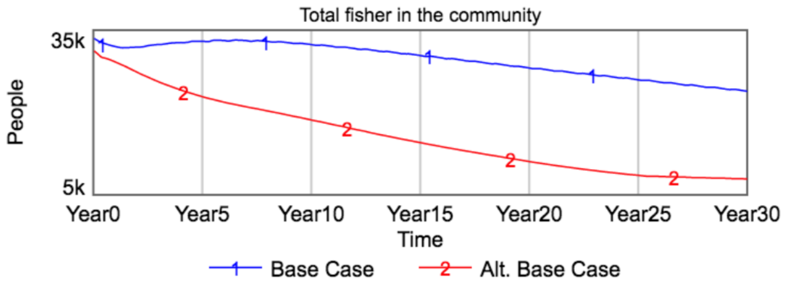
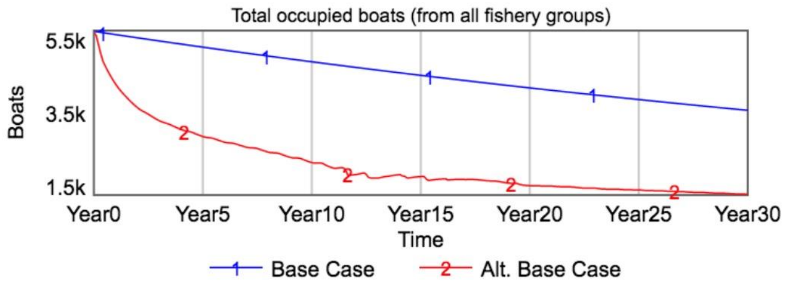
A.
B1.




B2.


C.</td><td>The household financial hardship will take place despite that average local price of all of the three fish groups is higher than the base case (A, only predatory is shown here).

Fish price will be higher since, under the ABC model, local fish supply will be lower than the base case. However, the applied dimensionless relationship between price and demand, at the same time, will suppress the local demand for fish. Therefore, the rate of local fish demand and supply will be almost proportional (B1, B2) and episodes of unsold fish will still occur (C).</td></tr>
</table>

No.	Comparative line graphs of the simulation outputs	Behaviour description
2.	 **A.**  **B.**	Finally, similar to the base case output, the number of Selayar fishers and occupied fishing boats will be declining, however, more drastically.

6.6 Discussion

In relation to the fixes that fail archetype (BOTG: Figure 5-48), the *problem symptoms*[19] of deficit and debt will be persistently experienced by fishing households despite their ability to maintain *quick fixes* from the consistent stream of income from fishing. Yet, at social scales that are larger than that of the household, the intensity of fishing reinforces *additional consequences* of the continuing decline of the inshore fish population as well as its habitat due to uncontrolled destructive fishery groups. Future problem symptoms (e.g., debt and deficit) may be lower than those projected if the inflation rate is lower than estimated, which makes basic household needs more affordable. The decline in natural resources can be highly undesirable since the collapse of some or all the fish groups in the habitat is a plausible outcome. This relates to the additional drivers not considered in the model such as those of fish habitat degradation (e.g., due to increasing pollution on the inshore habitats, mangrove deforestation, alteration of seagrass habitat area) and/or of fishing intensification (e.g., through the addition of local fishing boats, the extraction by non-Selayar larger vessels, influx of fishers from other regions) taking place in the future.

The shifting the burden archetype (BOTG: Figure 5-50), assumes that the supplementary source of income is negligible. Households are projected to increase their *livelihood specialisation* in fishing although the occupation is not economically productive in terms of alleviating the economic *problem symptoms* in the long term. This is depicted, for example, by the gradual increase of the average hours spent by fishers to maintain fish landings over the period. In

[19] Text in italics refers to the key variables in the behaviour-over-time graphs (BOTG) associated with the archetypes discussed earlier in Section 5.6.4.

combination with a decrease in weekly average fish price (and thus, fishing revenue) household deficits are set to increase. The plausibility of these trends relates to the limits to growth archetype (BOTG: Figure 5-52) since the *underperformance* of a fishery is likely hard to avoid in the future, especially if there are limited options for abating the socio-economic *constraints* for households (e.g., dealing with locally-restricted fish buyers, reliance to destructive fishing practices, and/or low capacities for improving the productivity of non-fishing livelihoods and/or diversifying income.

One unanticipated outcome under the base case assumption is that the tragedy of the commons (BOTG: Figure 5-54) is partially reflected in the behaviour of traditional and destructive groups that allocate most of their fishing hours to reef and seagrass areas. It was found that the *common resources* that will likely experience depletion are fish populations in the seagrass habitat, mainly resulting from a reduction in the seagrass carrying capacity (CC) due to cyanide fishing. Hence, as a measure for the *gain per activity*, the total rate of fish catch from seagrass follows the same declining trend.

However, the total fish population from the reef area is increasing steadily for these groups despite the declining CC of the living substrate area due to blast fishing. This unanticipated behaviour was found to be related to the CC of the rubble area. In this situation, the increase of CC in the rubble area due to blast fishing compensates for the loss of CC caused by blast fishing. This maintains the CC of the total reef area above the total rate of fish extracted from the reef by all fishery groups. Coupled with the allocation of fishing hours that are largely in the reef area, as a result, the overall rate of the catch of these inshore fishery groups increases over time (Figure 6-17).

As a result, a revised assumption was proposed which takes into account the observation that coral rubbles are irregularly located (i.e., patchy) amongst the living substrate areas. Therefore, the CC for fish of rubble area is also under the influence of water quality (e.g., the total suspended solid level that influences fish survival) and grazing by fish (e.g., herbivorous fish as the prey that attracts other predatory species). To reflect this, the CC of the rubble area was then adjusted by the *reef condition* index value (stock) as. To test this, the equation of the *living substrate CC for adult fish* and *living substrate CC for juvenile fish* converters was modified as follow: `normal CC per m2 of rubble * RUBBLE AREA / hectare in a square meter * REEF CONDITION`. As a result, the reef condition index (2016) value lowers the CC of the rubble area.

With the adjustment, the behaviour of the reef-related resource variables corresponds to the hypothesised first phase of the tragedy of the commons (BOTG: Figure 5-54). Referring to Figure 6-46, the CC of rubble for adult fish (also juvenile, not presented here) is estimated to decline slowly (i.e., *commons resource*, graph 2). The same pattern is estimated for the overall rate of fish extraction of all fishery groups (i.e., *gain per activity*, graph 3) and therefore similarly for the rates of local fish supply (not presented) that however, at a level lower than the results under unadjusted CC. Another noticeable difference was that fish price is estimated to increase slowly after the mid-period however, only at the peaks; or throughout the period (HR, PR, SQ, respectively; Graph 4). However, the price increases are insignificant relative to the initial value and the time horizon. Correspondingly, trends of the household financial variables were similarly projected to reflect underperforming fishery (as discussed earlier) despite the gradual increase of the average fishing hours of all fishery groups (i.e., *total activity*).

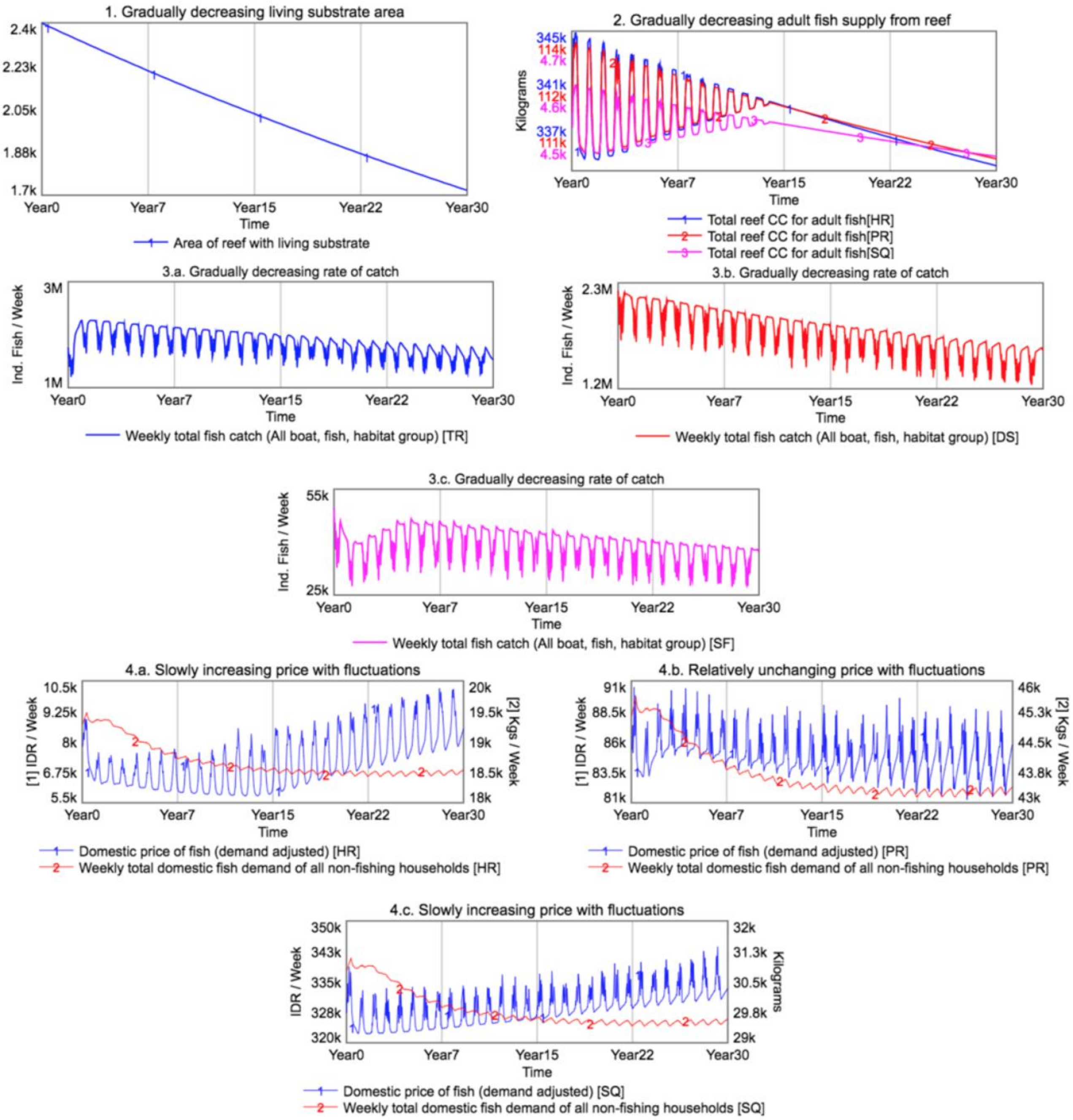


Figure 6-46. Key outputs of selected variables simulated under the base case parameters with a different value of carrying capacity of rubble area that is adjusted by the reef condition index.

In summary, the results presented here highlight attributes of ecological resilience that are pertinent to the 'declining reef fisheries'. In relation to the path-dependence archetype (Section 5.6.4.5), the projected three-decade dynamics of the state variables generally reflect the hypothesised future problematic trends, hence, a strong indication of future reinforcements to both undesirable social and ecological state changes. In relation to the phases of the path-dependence process (Section 2.2.4), under the base case parameter boundary, our model suggests that a lock-in state (i.e., phase III, Figure 2-5) of an undesirable livelihood regime might already be in place, or is likely to take place. This can be explained by the projected dynamics that generally exhibit stable dynamic equilibria (with reference to Figure 2-6).

However, this outcome may be an overestimation given that a ‘pre-lock-in’ stage involving non-ergodic social/ecological changes (i.e., phase II, Figure 2-5) is potentially more relevant to the real-world condition. This can be reasonably assumed given a large number of the base case parameters for variables that are exogenous to or uncontrollable by the problem owners are not static, or highly more dynamic, in real life (e.g., socio-economic goals and priorities of the households, market and trading conditions, physical environment: Table 5-5). In addition, there are uncertainties due to the exclusion of other social/ecological influences originating from a different temporal and spatial scale (e.g., excluded variables: Section 6.1.2.21), which involve a combination faster- or slower-changing variables that can further vary the estimated rate and level of the problematic dynamics.

On the other hand, when uncertain exogenous influence is taken into consideration (i.e., the alternative base case: Section 6.5.2), the projected problematic systems behaviour may be an underestimation. With the influence of fish extraction by non-Selayar fishers incorporated, there is a possibility that the system enters the undesirable lock-in phase earlier than it is previously expected (i.e., the base case). Although hypothetically parameterised, the outcome of the alternative base case model (Section 6.5.2) emphasises that the focus of the problem management or the development of solutions should not be solely on the Selayar-based fishing activities. By addressing other drivers of local fish scarcity, such as regulating the operation of non-Selayar fishing vessels, the risk of unintended consequences (e.g., local economic stresses: output behaviour no.2 in Table 6-5) may be able to be minimised or avoided. The improvement of surveillance and/or enforcement capacity that was perceived to be necessary (e.g., *surveillance skills / authority / equipment / capacity / enforcement*; agreed in all 15 FGDs, Table 1, Appendix 12) to secure the fishing territory of Selayar small-scale fishers (i.e., within four nautical miles from the coast) is, therefore, a critical policy direction.

Overall, the findings from the dynamic modelling have addressed the questions of Main Assessment 2 (Section 2.4) by simulating the flows of materials and information that influence problematic livelihood dynamics due to the influence of the social, economic, and ecological drivers represented in the base case parameter. It also quantitatively addresses Question 1 of Main Assessment 3 (Section 2.4) by estimating the rate and distance of the system from the thresholds that define an undesirable livelihood configuration.

Chapter 7 Testing of policies and strategies

Overall, the previous chapters constructed a detailed account of the livelihood problems associated with the Selayar fishing communities (Chapter 4). This summary also attempts to describe the complex systems structure and relationships between feedback variables that maintain the problematic behaviour of the livelihood state variables (Chapter 5), enabling the reproduction of these behaviours using a simulation-based model developed with the team (Chapter 6). In Chapter 7, I explore several policies that have the potential to modify the behaviour of the state variables and test these using the simulation model to screen the most promising entry points to solve specific livelihood problems. Section 7.1 describes the design, modelling, and individual simulation testing of three proposed policies, which are (1) introducing alternative sources of income to households that otherwise depend on fishing, (2) reducing the fishing effort of destructive fishing groups, and (3) improving the marketability of local fish catch. Section 7.2 describes testing combined simulated intervention policies as part of further exploration into their effectiveness. Section 7.3 includes testing combined policies in scenarios of habitat capacity that are likely to be impacted by moderate to high rates of projected climate change.

7.1 Outputs from policy modelling

7.1.1 Policy designs

Several Decisions variables (i.e., variables perceived as a problem intervention) identified in the 'problem mapping' activity received consensus feedback in the FGDs. These included variables that reflected the potential need for surveillance and enforcement of legislation concerning destructive fishing activities (e.g., *surveillance skills / authority / equipment / capacity / enforcement*; agreed in all 15 FGDs, Table 1, Appendix 12), alternative livelihood development (e.g., *household-scale industry*; agreed in up to 13 FGDs), coral reef area management (e.g., *coral reef rehabilitation*, *marine reserve/protected area;* agreed in up to 13 FGDs), and changes to the marketing of fish products (e.g., *marketing, fish product export/marketing support;* agree in up to 8 FGDs). In relation to the need for marketing, variables that reflect the standard of living for households (e.g., *savings, deficit, expected costs of living*) are sensitive to the variable that controls *human population* (e.g., parameter no.18). This was attributable to the base case assumption that local fish demand (i.e., reflected in sales) is solely dependent on local household consumption behaviour from the non-fishing population. With regard to alternative livelihoods, the standard of living was also sensitive to parameters that influence household income stream and the costs of living/fishing. For example, parameters that define fishing effort (e.g., catch per unit of effort: no.5, 4) and financial obligation (e.g., fishing costs: no. 85, household size: no. 16) are influential to either *savings, deficit* and/or *debt.* These findings further support that household income improvement that relies on an alternative livelihood activities that aimed at fishing intensification would be a policy that is counterproductive to the alleviation of the topic problem (see: Section 5.6.4.3, Chapter 5) and has a risk of reducing the standard of living beyond the households' boundaries of control.

Based on these findings, three policies were tested using the dynamic model described and developed in Chapter 6:

- Policy 1: Develop alternative livelihood for additional income source to fishing households; and
- Policy 2: Improve surveillance of the destructive fishing activities; and
- Policy 3: Improve marketing of the local fish landings.

In relation to Policy 1, the majority of published literature has highlighted the relative importance of improving supplementary income for fishing households (i.e., beyond fishing-related ancillary activities) to enhance the capacity of small-scale fisheries (SSF) to 'adapt' to undesirable social and/or environmental changes (e.g., Béné, Macfadyen and Allison (2007); Cinner (2014); Finkbeiner (2015)); Marschke and Berkes (2006)). Results from the reanalysis of the household survey dataset suggest, however, that supplementary non-fishing work associated with fishing households on average generated lower income relative to fishing; and, for some fishing household groups, it was an unprofitable activity (i.e., value difference between the average costs and revenue of non-fishing work: variables no. 119 and 121, respectively, of household respondent no 2,3,4; in Appendix 17. In terms of Policy 2, the combination of these policies could fortify an existing community-based conservation strategy given the established community-based surveillance groups in Selayar (the *Pokwasmas*), (e.g., Berkes (2007); Finkbeiner (2015)). Economic developments or incentives play an important role in empowering local resource users to self-regulate or limit their harvest activities (Campbell et al. 2013; Niesten, Gjertsen & Fong 2012; Pomeroy, Katon & Harkes 2001). Policy 3 is surprisingly relevant to addressing the hypothesised restriction of fish sales revenue due to the oligopsonistic local market (i.e., limits to growth archetype, Section 5.6.4.3)

7.1.2 Application of Policy 1: Alternative livelihood development

Policy 1 was represented in the stock-and-flow model using the *profit of non-fishing unit* variable. This variable positively influences the *household income addition* rate (inflow) in the Household Net Income sector. The average weekly profit of agricultural-based activities of the main income source of the non-fishing household in Selayar (Appendix 17) was used as a proxy for a 'locally viable' alternative livelihood scenario for policy 1. The base scenario was set as a weekly profit from one non-fishing unit fully operating as a primary source of income (i.e., using a larger portion of the labour hours in the household). This was referred to in the model as ‘normal profit’. For the application of Policy 1 as the base case model, each fishing household type was assumed to have a different capacity to operate the non-fishing business unit, and thus, different weekly non-fishing profit, which is referred to as the ‘actual profit’. The actual profit was set as a function of: (1) the normal non-fishing profit, (2) the actual savings allocated non-fishing operational costs, (3) the total labour hours available for non-fishing activities after hiring, (4) the fraction of labour hours from the household member in the occupation, and (5) rate of gradual delivery of the actual profit.

Policy 1 was applied using an additional stock-and-flow structure as illustrated in Figure 7-1. The detailed structure representation in the Stella® software, and the input values and Stella® equations embedded in the structure are presented in Appendix 30.

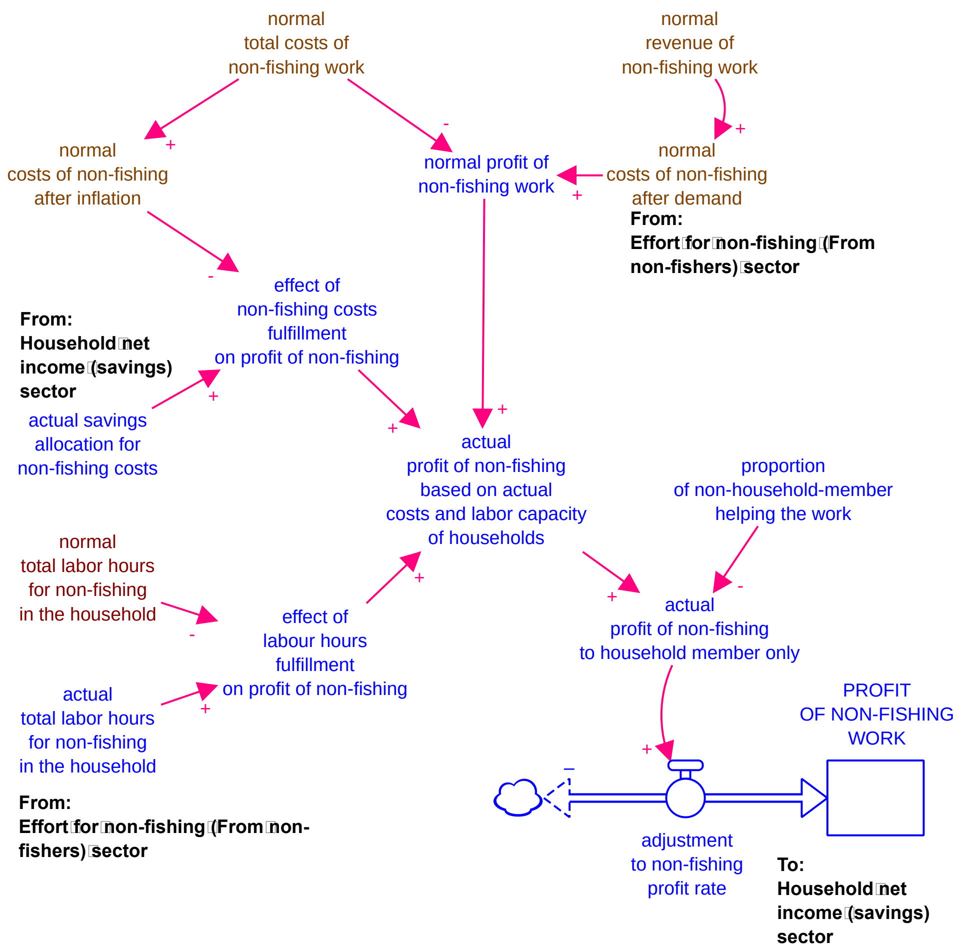


Figure 7-1. Model structure for Policy 1 that was added to the base case model structure.

7.1.3 Results and analysis of the base scenario of Policy 1

For the base scenario of Policy 1, it was assumed that:

1. The average weekly costs and revenue represent the normal non-fishing profit, and labour hours of the income-generating activities of the non-fishing (mainly agriculture) household

respondents in 2016 (i.e., Bio-LEWIE dataset: Variable no. 119, 120, 121 under 'Non-fishing HH' in Appendix 17).

2. The full-extent delivery of the normal profit (i.e., the normal weekly profit) takes place if the normal value of costs and labour are fulfilled (i.e., the normal requirements). That means that the ratio of the actual (i.e., available) to the normal (i.e., the required) value of costs, and also of labour hours, should be one.
3. The maximum business unit that the household can manage as the main income source is two. This means that even if the actual costs and labour hours are four times the required costs and labour hours (i.e., the normal hours), the maximum weekly profit would only be twice of the potential profit (i.e., the normal profit). This assumes that, despite labour hours outsourced by households, there are infrastructure limitations to household enterprise expansion such as those resulting from the limitation of the availability raw materials or of the size of the workplace (e.g., agricultural area).
4. The policy is introduced in year 1 (2016-2017) and the period of gradual profit delivery is fifteen years after the time of policy introduction with a linearly increasing rate (i.e., normal profit / (52 weeks * 15 years)). The delivery period was hypothetically considered as a viable time frame to allow for the adoption and initiation of non-fishing work (i.e., agriculture-related) until fishing-based household members reached the optimal competency in work (i.e., the normal level).
5. External influences that may influence a change in the normal profit level, such as annual inflation (i.e., cost increases) and non-fishery product/service demand (i.e., revenue changes) were excluded.

The results show that application of the base scenario of Policy 1 in the base case model will allow fishing household groups to deliver a steady weekly profit from non-fishing work of about IDR 4,000,000 around year 15 (Figure 7-2). In general, improving income stream from alternative livelihood would promote both desirable and undesirable response behaviours of the other state variables relative to the outcomes of the base case simulation (Chapter 6). The key behaviours are summarised in Table 7-1.

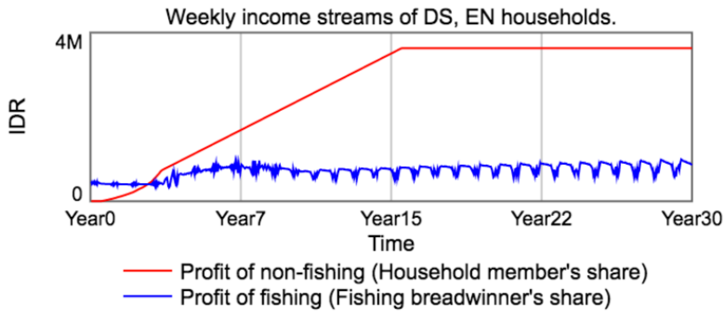
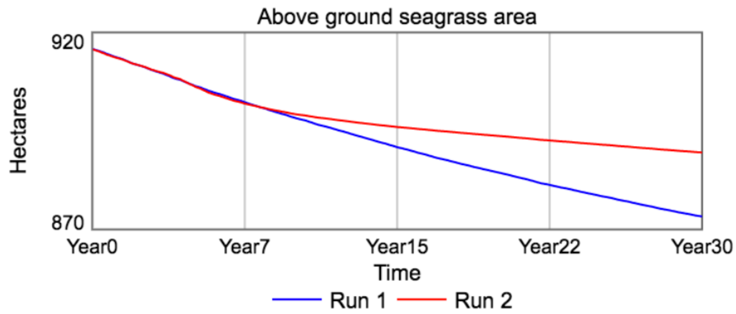
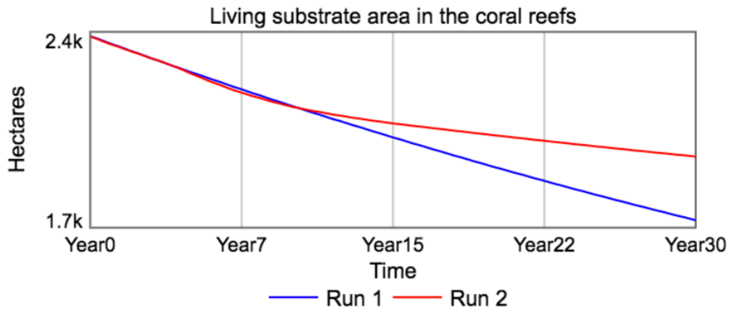
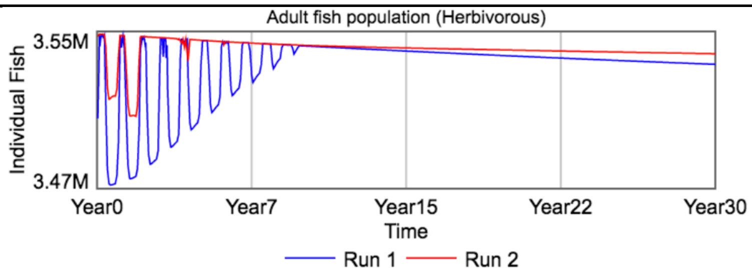
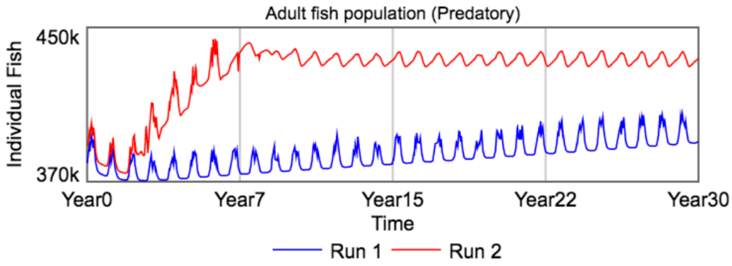
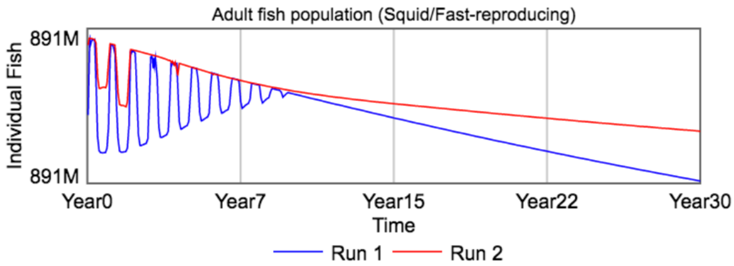
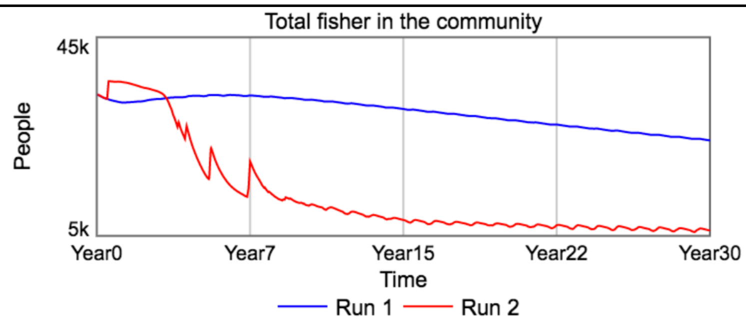
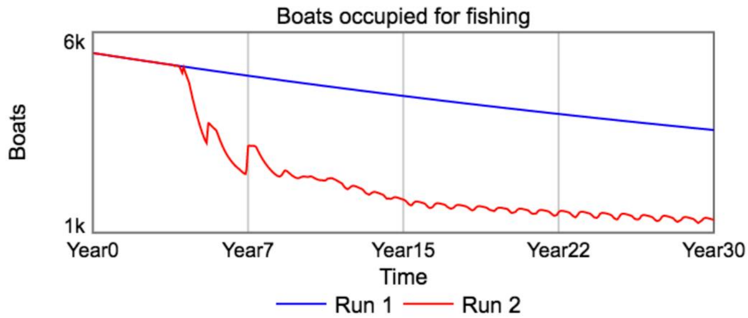
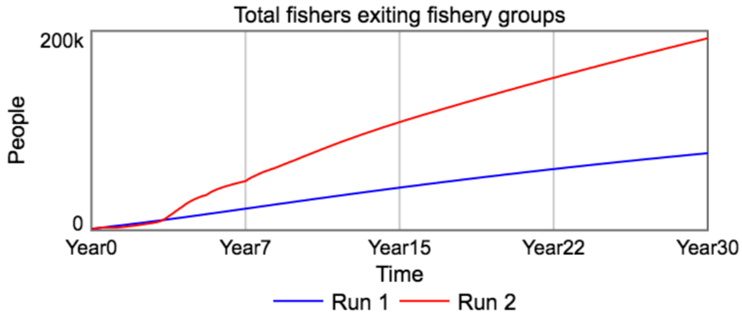


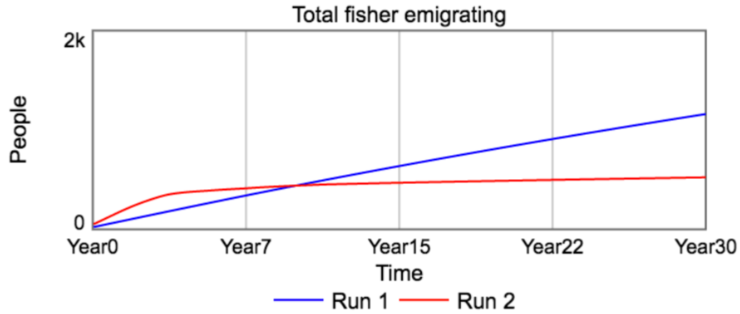
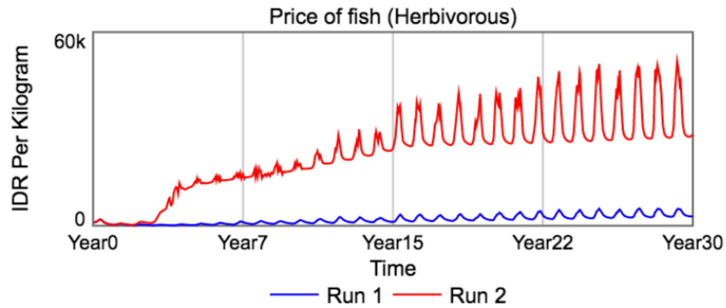
Figure 7-2. Weekly additional income from non-fishing work based on the base scenario of Policy 1.

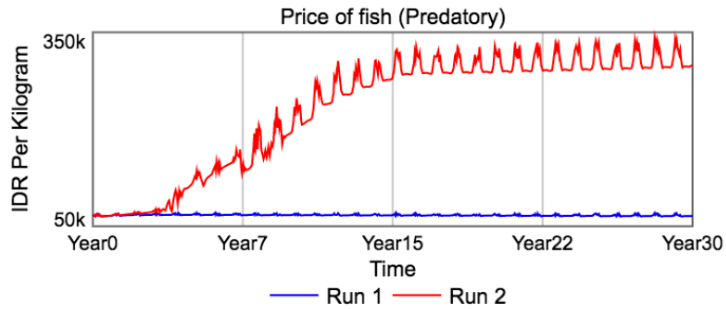
Table 7-1. Comparative line graphs showing output behaviour of the state variables before and after applying the Policy 1 base scenario (Run1 and Run 2, respectively).

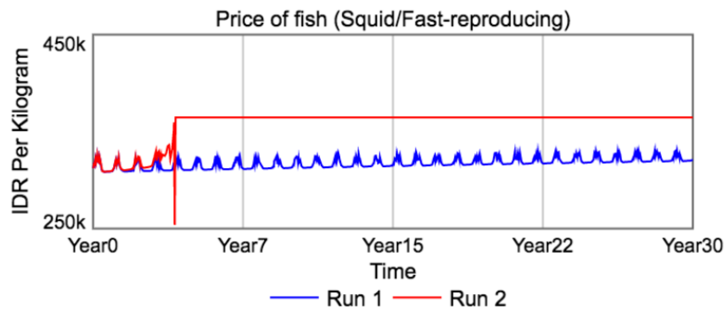
No.	Comparative line graphs of the simulation outputs	Behaviour description
1.	 	Seagrass area and reef living substrate area degradation will be suppressed, but the decline would be ongoing.
2.		The total fish population (from all habitats) of HR and SF fish types would still be declining gradually but at a slower rate. PR would gradually increase, but at a higher range. Fish population will fluctuate in the first half of the simulation period, for HR and SF, and throughout the time horizon, for PR. The fluctuations are maintained differently due to the

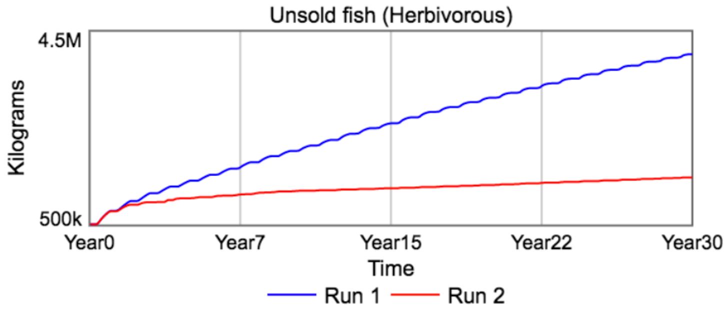
No.	Comparative line graphs of the simulation outputs	Behaviour description
		combination of annual and weekly oscillations. On an annual basis, the ‘spikes’ occur due to the recuperation of the fish stock towards the optimum level based on the current total carrying capacity of the fish habitats, which is allowed by reduction of fishing activity during the weather disturbance period (i.e., west monsoon). On a weekly basis, the through level of the oscillation may increase over time (i.e., approach the carrying capacity) when there are more episodes of higher rates of fish recovery (i.e., juvenile recruitment and maturation) than the total rate of fish extraction, and the opposite condition for decreasing trough level.
3.		The total number of fishers in the community will decline more rapidly in the first seven years following policy implementation. The number of occupied boats will follow the same trend several years later. The fisher decline is mainly triggered by the higher rate of labour exiting fisheries and of emigration of fishers. These rates will receive higher positive influence from both the profitability of non-fishing work overfishing (i.e., the primary livelihood of fishers/households are no longer fishery-based) as well as education capacity (i.e., more household can finance and thus allocate more time for tertiary education activity or learning another career).

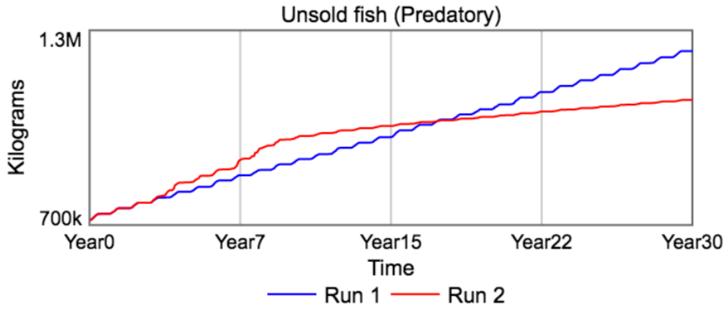
<table>
<tr><th>No.</th><th>Comparative line graphs of the simulation outputs</th><th>Behaviour description</th></tr>
<tr><td></td><td>

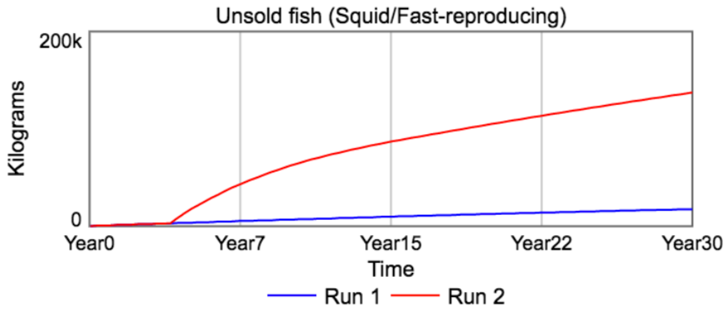

</td><td></td></tr>
<tr><td>4.</td><td>

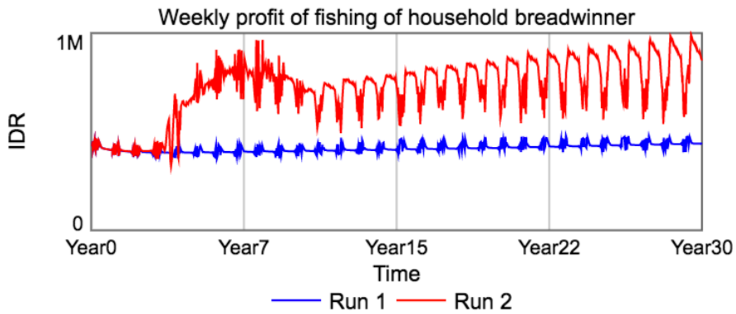


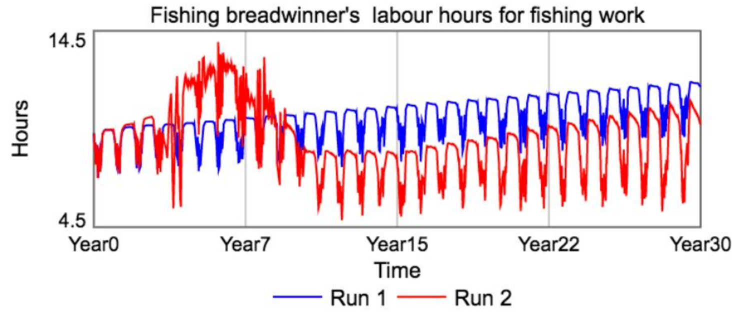
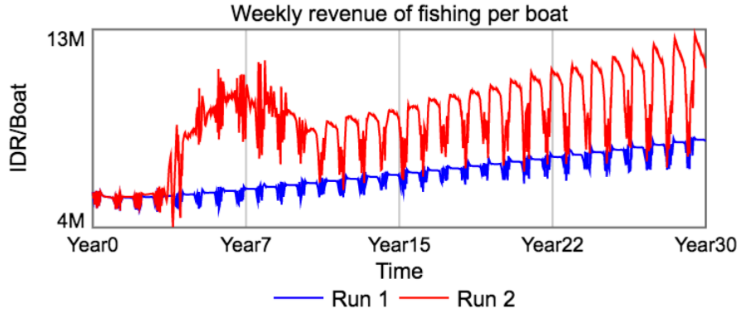
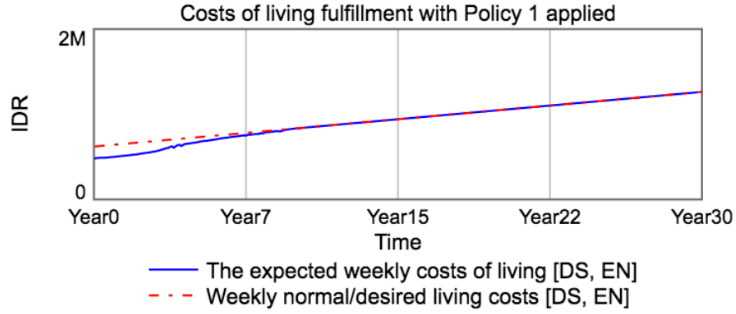

</td><td>The local prices of all three fish types will increase significantly mainly due to local undersupply of fish prompted by the diminishing fisher population. The price of SQ will be maintained at the ceiling level (i.e., 10 times the normal price).</td></tr>
</table>

<table>
<tr><th>No.</th><th>Comparative line graphs of the simulation outputs</th><th>Behaviour description</th></tr>
<tr><td>5.</td><td>

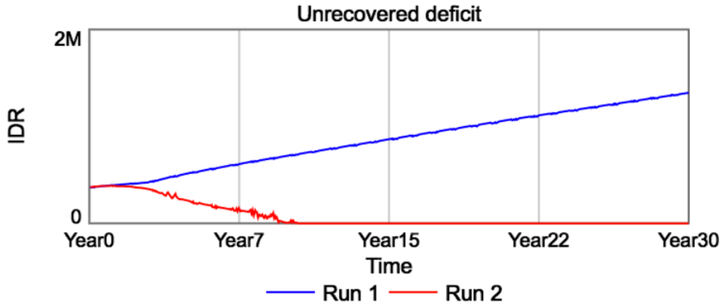


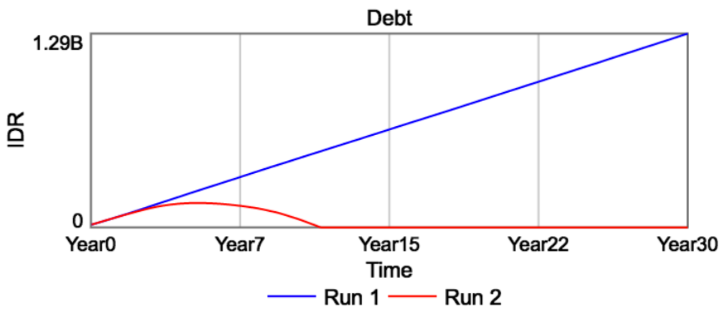

</td><td>Despite the increase in price, the increasing fish consumption of non-fishing households (i.e., by the non-fisher population) will drive a higher consumption of HR and PR fish (i.e., less unsold fish).

Interestingly, for SQ fish, the soaring fish price will occur alongside the increase of unsold fish. In this case, the price-demand relationship in the model assumes that the price level is too high relative to the normal level, which will therefore cause a slump the local demand, assuming that there are cheaper alternatives for SQ.</td></tr>
<tr><td></td><td>
</td><td>The average profit of fishing of households will be maintained at a higher level over time. Shown here only from the destructive with larger engine fishing group.</td></tr>
</table>

No.	Comparative line graphs of the simulation outputs	Behaviour description
7.	 	Interestingly, the fishing profit increases at the same time the average hours of fishing diminish. This can be associated with the increase of fishing revenue which is mainly due to the increasing prices of PR and HR fish; and the increasing catch per unit of effort is due to the improved condition of fish habitat and/or population.
8.	 	The total rate of income will allow households to dramatically increase their spending allocation for costs of living and allow them to meet the standard of living (i.e., *the desired/normal costs of living* base case parameter).

<table>
<tr><th>No.</th><th>Comparative line graphs of the simulation outputs</th><th>Behaviour description</th></tr>
<tr><td></td><td>



</td><td>Household savings will be able to be maintained as an increasing trend starting at around year 7, which is when the average weekly non-fishing profit exceeds fishing profit.

Yet in the real world, the accumulation of the community's net income would be finite as monetary assets would also raise the living standards and be translated into non-monetary assets (e.g., through purchasing/spending on household goods, community infrastructures).

Starting at a similar point of time, episodes of deficits will cease, and existing debts will be resolved.</td></tr>
</table>

The Policy 1 testing demonstrates the potentially desirable improvement in overall productivity (i.e., profit) of the supplementary livelihood activity of the fishing households in overcoming their poverty traps (i.e., the resolution to persisting debt and deficit if Policy 1 is absent [i.e., base case]). Despite the fact that households will keep fishing with a far lower allocation of labour hours, the intensity of destructive fishing would still suppress recovery of both the fish habitat and the fish population. This highlights the potential value of applying the substance of Policy 2.

7.1.4 Application of Policy 2: Improving surveillance

Policy 2 manipulates the *surveillance effort index* stock. The normal level of surveillance (the condition in 2016) was defined by the index value of 1. A policy for hypothetically improving surveillance was defined within the base scenario of Policy 2. Surveillance 'improvement' was assumed to include an increase of surveillance activity as well as effective law enforcement that aimed to deter illegal destructive fishing activity (Crawford et al. 2004). The policy positively influences the exit rate of fishers from the destructive fishery stocks to the non-fishing population, and of the fisher movement away from the destructive fishery to the other two groups (traditional and squid/pelagic). At the same time, the entry rate of fishers from the non-fishing population into the destructive fishery stocks, and the fisher movement from the other two groups into the destructive fishery, drive an opposing trend. In the model, these rates were modified by multiplier effect values, which were a function of the ratio of the actual to the normal index using graphical converters.

Policy 2 was applied using an additional stock-and-flow structure as illustrated in Figure 7-3. The detailed structure representation in the Stella® software, and the input values and Stella® equations embedded in the structure are presented in Appendix 31. Referring to Figure 7-3, the *week counter* stock renders the week number as an input of the period of surveillance improvement in the graphical function of the policy trend (Figure 7-4). The output value from the surveillance trend then adjusts the actual (this week's) *surveillance effort index* information stock. The ratio of the actual to the normal (i.e., initial) surveillance effort index serves as a dimensionless multiplier value that modifies the aforementioned rate of fisher movement and entry/exits.

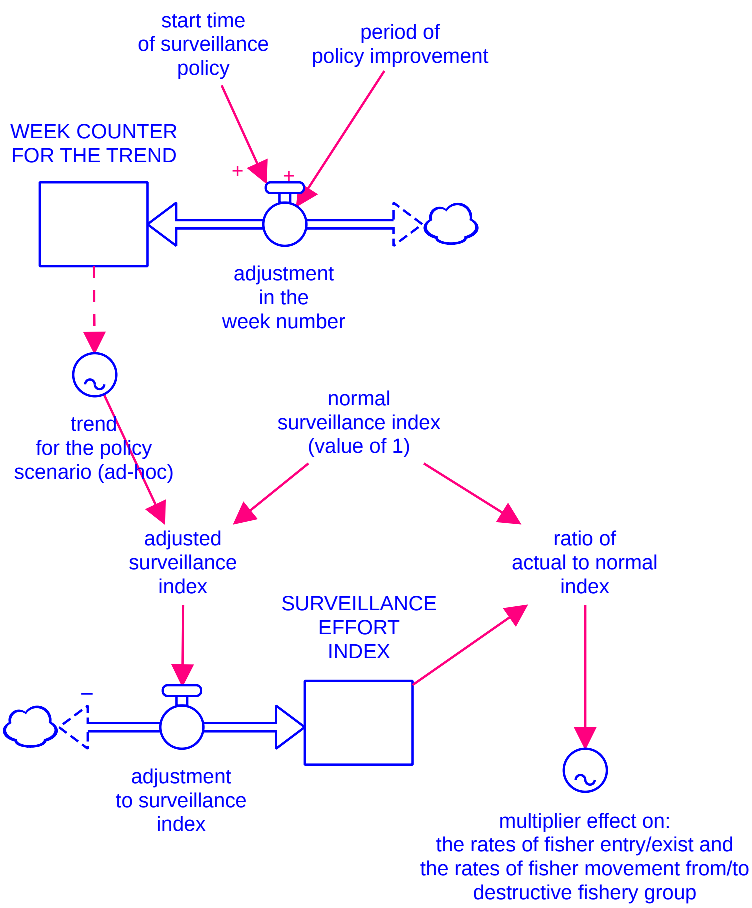


Figure 7-3. Model structure for Policy 2 that was added to the base case model structure.

7.1.5 Results and analysis of the base scenario of Policy 2

For the base scenario of Policy 2, it was assumed that:

1. The normal (i.e., initial) surveillance index assumes that there is no surveillance activity; hence, no reduction effect on the rate of fisher movement and entry/exits linked to destructive fishery group.
2. The year when the policy is introduced is as early as within year 1 (2016-2017).
3. The trend of surveillance improvement policy is represented by a hypothetical s-shaped increasing trend as illustrated in Figure 7-4
4. The improvement in surveillance is implemented for over 5 years (260 weeks), reaching a maximum surveillance index of 100 over this period.

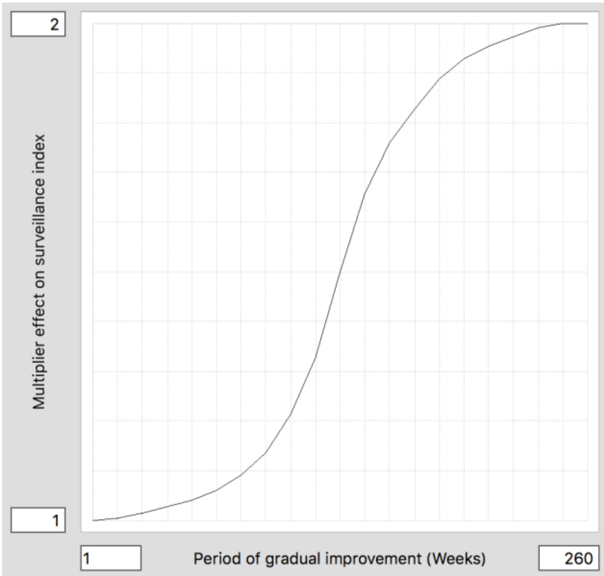


Figure 7-4. Hypothetical s-shaped growth trend of the surveillance effort for the base scenario of Policy 2.

The application of the base scenario of Policy 2 would generate a five-year surveillance index improvement trend as shown in Figure 7-5.

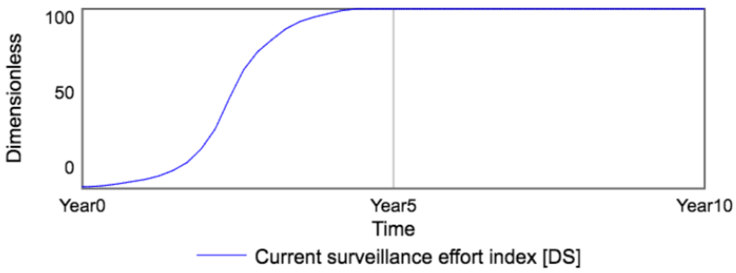
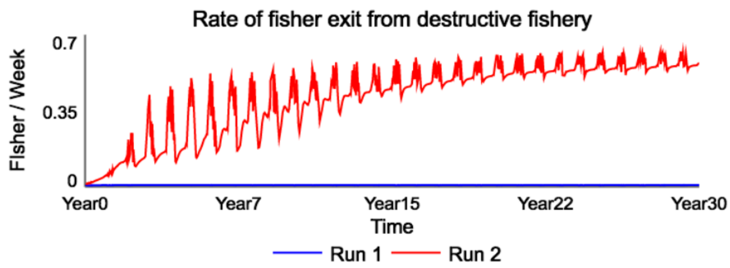
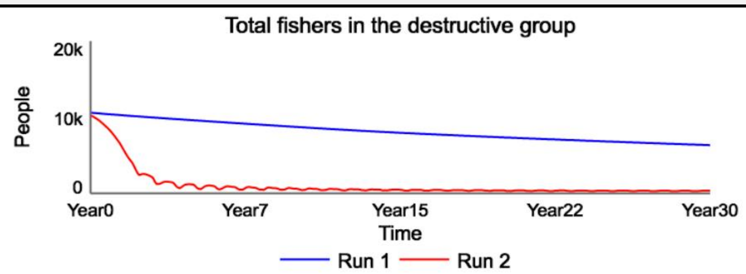


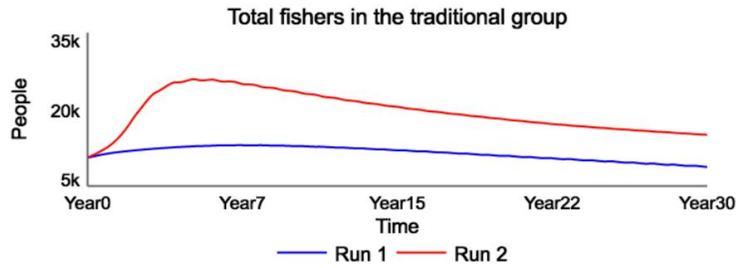
Figure 7-5. The s-shaped trend of the hypothetical increasing multiplier effect value representing the five-year surveillance index improvement for the base scenario of Policy 2.

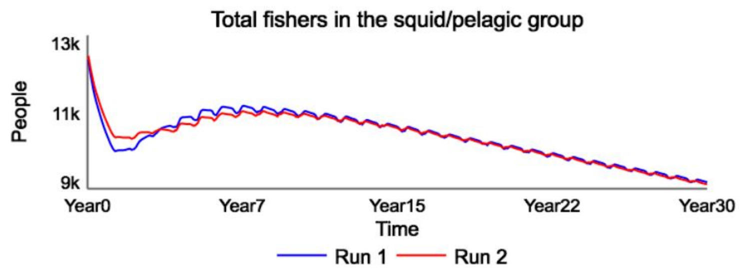
In general, increasing the surveillance index to 100 over 5 years would reduce the number of destructive fishers (i.e., key outputs no.1, 2) and would, therefore, tend to reduce the overall decline in habitat quality while sustaining the fish population (i.e., key outputs no. 3, 4). Interestingly, these ecological improvements have social repercussions given that they would also trigger an increase in fishing activity of other groups (e.g., higher fisher in traditional groups, in no. 2) and in the community (e.g., higher total fisher, in no. 5). Referring to the graphs in no. 5, this relates to the improving fish resource that will increase the average fishing profit for better cost of living fulfilment (1st graph). Under the base case parameter, the improvements in the profitability of fishing increase the total entry of non-fishing population – which otherwise offset the total exiting fishers due to the surveillance (2nd, 3rd graphs). As a result, under the application of Policy 2, the total number of fishers would increase slightly above the base case (4th graph). Furthermore, under Policy 2, the change in fish price trend will be relatively similar (i.e., key output no .6) and thus the base case problem of the price suppression associated with the oversupply of local fish will persist. Consequently, fishing households, in general, would still fulfil the costs of living below the hypothesised poverty line (i.e., key outputs no.6).

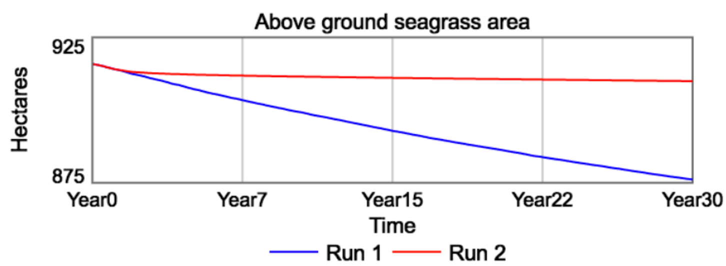
Table 7-2. Comparative line graphs showing output behaviour of the state variables before and after applying the Policy 2 base scenario (Run 1 and Run 2, respectively).

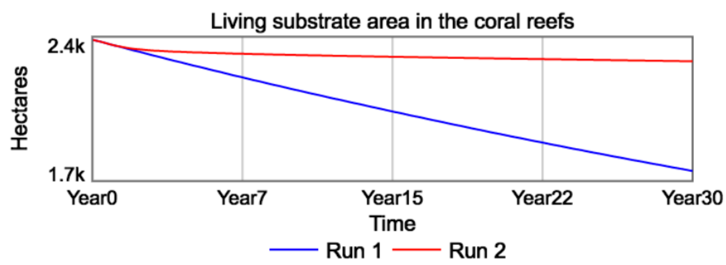
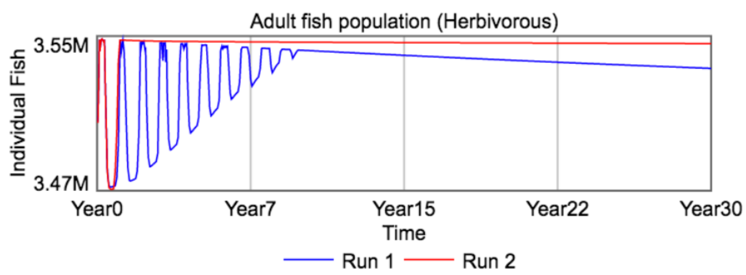
No.	Comparative line graphs of the simulation outputs	Behaviour description
1		Surveillance improvement would increase the rate of fisher exiting the destructive fishery.

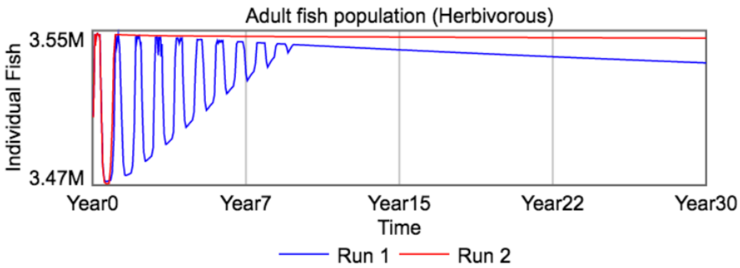
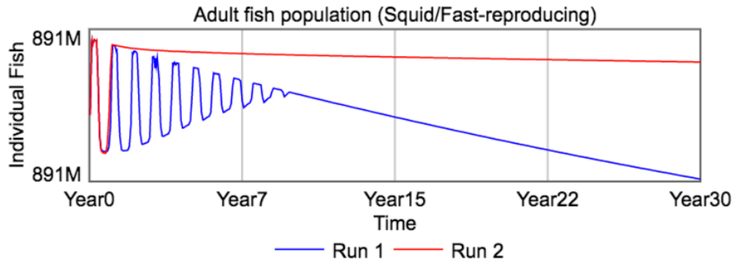
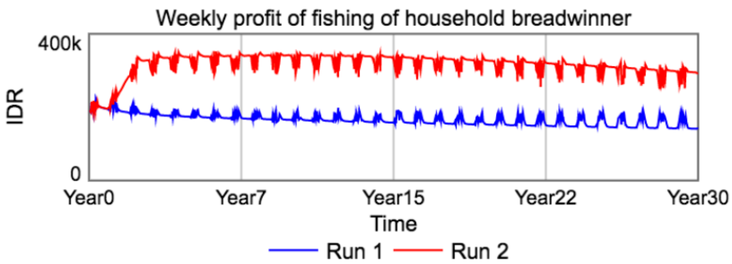
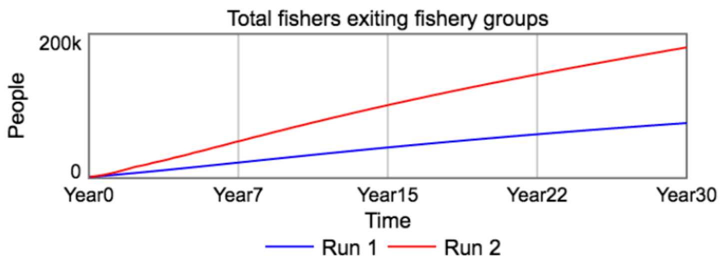
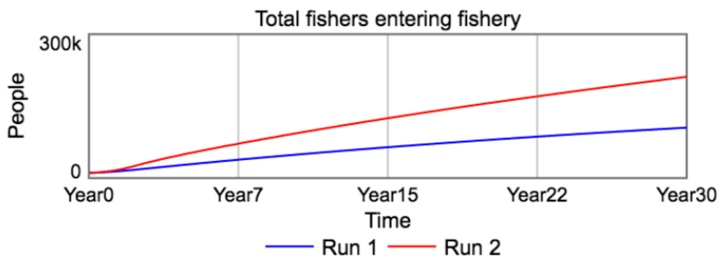
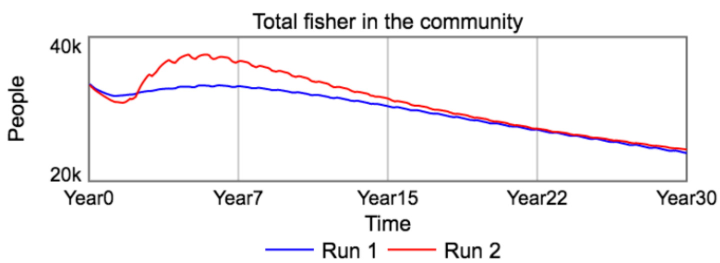
<table>
<tr><th>No.</th><th>Comparative line graphs of the simulation outputs</th><th>Behaviour description</th></tr>
<tr><td>2</td><td>

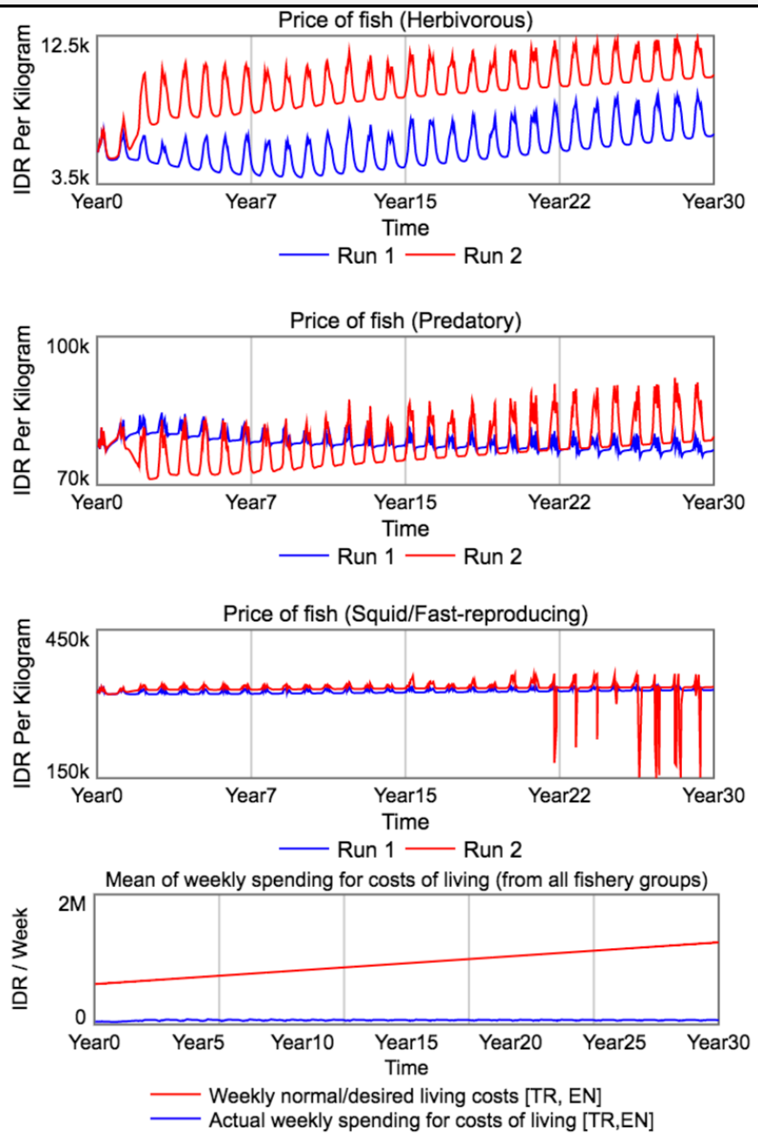



</td><td>At the same time, the rate of fishers shifting away from the destructive group also increases and destructive fishers are greatly reduced during the policy improvement period.

However, the comparative profit between the fishery group tends to mobilise more ex-destructive fishers to the traditional group than the squid/pelagic group.</td></tr>
<tr><td>3</td><td>


</td><td>Despite destructive fishing would still be operating at a far lower level than the base case, the condition of the fish habitats affected by destructive practices would be maintained.</td></tr>
<tr><td>4</td><td>
</td><td>In accordance with the habitat conditions, the population of the fish classes will be preserved as some fish groups' gradual decline will be suppressed or sustained at a higher level.</td></tr>
</table>

No.	Comparative line graphs of the simulation outputs	Behaviour description
	 	
5	   	The improving fish resources would improve the average fishing profit gained by the households. Only the profits of the traditional group are shown here. Relative to the base case outputs, despite a higher rate of exit due to surveillance of destructive fishing, the rate of labour entering the fishery would also increase due to the profit improvement. The total fisher entries will be higher than the exit. As a result, although damage to fish habitat is significantly constrained, the number of fishers operating will be almost the same.

No.	Comparative line graphs of the simulation outputs	Behaviour description
6		Similar to the base case output, the price of fish would still be suppressed in general due to the increase of fishers at the same time improving catch per unit of effort due to fish population improvements. The average weekly spending on costs of living will be maintained at a lower rate than that of desired costs of living.

7.1.6 Application of Policy 3: Increased sale volume of local fish landings

Policy 3 involves the *effect of demand change* converter which produces multiplier effect values that then positively influence the total *non-fishing household fish consumption* value (as a proxy of local fish demand). The policy assumes that the local demand for fish can be developed further through marketing support such as for diversifying local fishers' and/or fisher groups' marketing channels (Gardner et al. 2017; Salmi 2015) to reduce their customary reliance on the local agents of international traders and/or local fish markets (Miñarro et al. 2016; Radjawali 2012). Policy 3 was applied using an additional stock-and flow structure as illustrated in Figure 7-6. The structure essentially generates a combination of an orderly fluctuating trend (e.g., sine (or cosine) curve) and a linearly increasing trend that defines the demand change. The detailed representation of the structure in the Stella® software, and the associated input values and Stella® equations embedded in the structure can be found in Appendix 32.

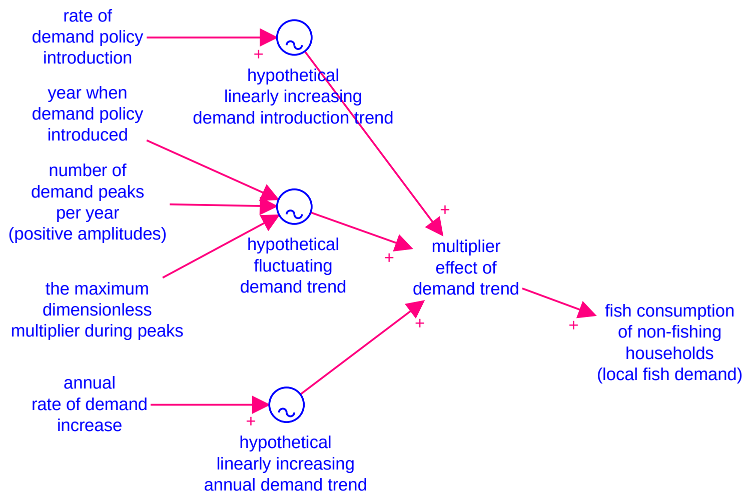


Figure 7-6. Model structure for Policy 3 (Improvement of the sales of local fish landings) that was added to the base case model structure.

7.1.7 Results and analysis of the base scenario of Policy 3

In the context of improved sales of local fish landings (Policy 3), it was assumed that:

1. Normal local demand gradually increases, linearly, up to three times of the normal value over two years of policy introduction. The rate assumes that marketing/supply chains will improve during this period through, for example, an increase in fish quality (i.e., the result of improved handling and storage) and of international buyers to trade directly with the local fishing communities. Therefore, the local fish price and export fish price can be at the same price rate (base case parameter: export fish price is 300% of the local price).
2. The year of policy introduction is as early as within year 1 (2016-2017), which is then followed with a two-year period of gradual policy introduction assuming that the improvement of fisher marketing capacity is not an instantaneous process.
3. The number of demand peaks per year is three, with each hypothetically increasing fish consumption by up to four times of the normal (i.e., initial) condition (i.e., the fractional range of 1 to 5). This assumes that local fishers are able to self-market the harvest to fulfil the regional and national demand for fish food (i.e., beyond the island) and accomodate to the annual fish demand increase triggered by three holiday periods (e.g., Chinese New Year and Christmas/New Year [i.e., due to increased fish food consumption], and Ramadhan [i.e., reduced regional fish supply due to fasting fishers]) that could increase up to four-fold. The trend is illustrated in Figure 7-7.
4. The demand annually increases at a fixed fractional rate of 3.5% (0.035) assuming that it is positively influenced the similar fixed rate of annual inflation of the year 2016. The

multiplicative combination of this trend and the hypothetical demand peaks is shown in Figure 7-8.

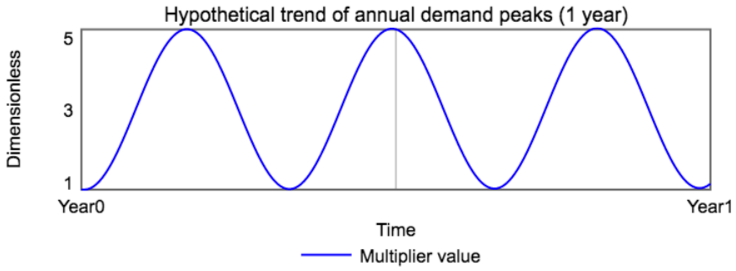


Figure 7-7. Hypothetical negative-cosinusoidal curves that represent the three annual demand peak events.

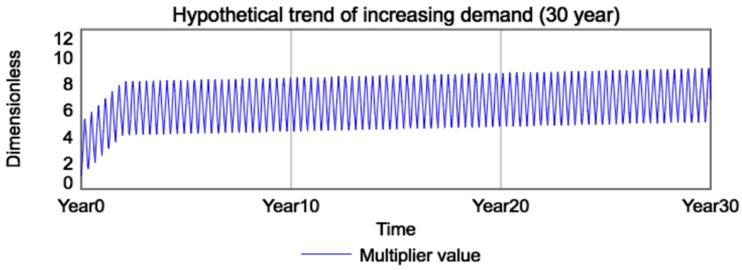


Figure 7-8. Hypothetical linear increase trend of the demand change.

The application of the base scenario of Policy 3 will directly maintain a higher fish demand rate (Figure 7-9) but, in general, the undesirable trends within the base case would remain. Despite a far stronger price resulting from an increase in demand (Table 7-3), the price will fluctuate within a range that remains steady over the time horizon (output no. 1), which is similar to the base case output. This results in an increase of the weekly fishing revenue/profit that renders higher spending for the cost of living fulfilment (output no. 2) yet would remain below the parameterised minimum living standards (output no. 3). Moreover, as fishing will be a more lucrative activity, the decline rates of fish habitat and population size would be higher (output no. 4).

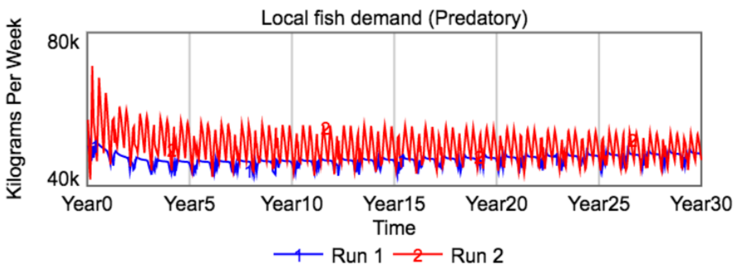
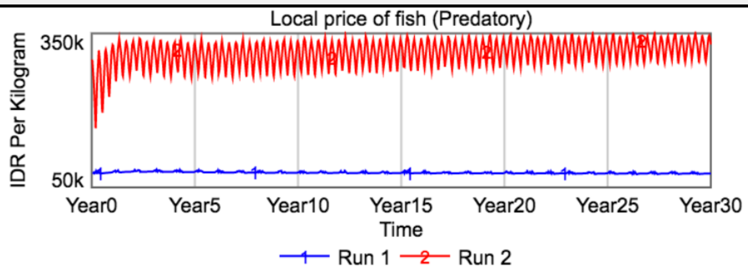
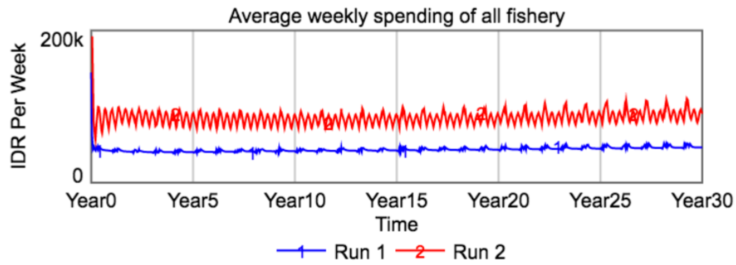
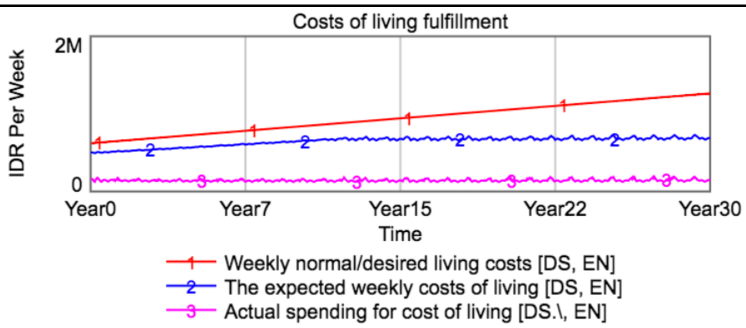


Figure 7-9. The weekly local price of fish of the predatory group without and with Policy 2 base scenario applied (Run 1 and Run 2, respectively).

Table 7-3. Comparative line graphs showing output behaviour of the state variables before and after applying the Policy 3 base scenario (Run 1 and Run 2, respectively).

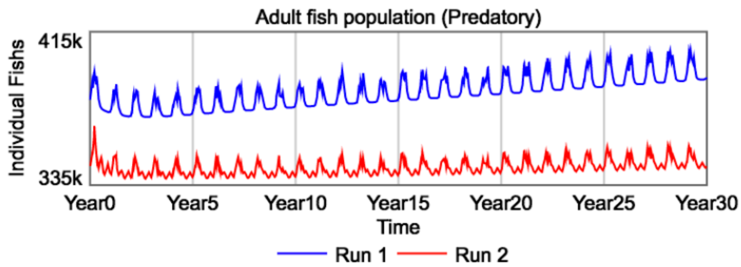
<table>
<tr><th>No.</th><th>Comparative line graphs of the simulation outputs</th><th>Behaviour description</th></tr>
<tr><td>1.</td><td>


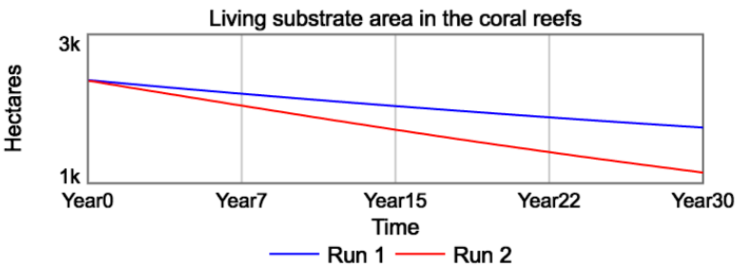
</td><td>The Policy 3 base scenario resulted in a higher local price rate of all three fish groups maintained at a plateauing trend. Only the predatory fish group is shown here.</td></tr>
<tr><td>2.</td><td>


</td><td>The Policy 3 base scenario resulted in a higher average cost of living fulfilment rate of fishing households from all fishery groups with a trend similar to the base case.</td></tr>
<tr><td>3.</td><td>


</td><td>The expected (i.e., adjusted by deficit) and the actual (i.e., further adjusted by debt) spending for costs of living would still be lower than the minimum living standards (i.e., the normal).

This condition would apply to all six fishing household groups (3 fishery group, 2 boat motor type).

However, only the results from the households in the destructive fishery using larger boat motors (DS, EN) fishing household are shown here.</td></tr>
<tr><td>4.</td><td>




</td><td>The fish population and its habitats would be maintained with a trend similar to the base case and however, at a lower level.

Only the predatory fish group and coral reef habitat are shown here.</td></tr>
</table>

In general, the system responses under the three policy settings improved the financial state of the households (Policy 1), reduced fish habitat loss and better preserved local targeted fish stock (Policy 2) and increased the monetary value of the local fish catch (Policy 3). However, the results of the policy analysis also suggest that total reliance on any one of these three policies will heighten the risk of the social-ecological trap increasing. This is mainly a consequence of each policy having a sizable risk of undesirable system behaviour(s), which is larger in the case of no action and most optimal when the three policy actions are applied together. The three-policy action case is explored in the next section.

7.2 Outputs from strategy modelling

7.2.1 Strategy designs

In this section and thereafter, the combination of the three policies presented in Section 7.1.1 is referred to as the 'Strategy'. The strategy was applied in the model using the same set of parameter configurations as the base scenario of Policy 1, Policy 2, and Policy 3 (Section 7.1.3, 7.1.5, 7.1.7). Three strategy variations were then developed by differentiating the time of policy introduction and the period of policy development; which is shown in Table 7-4.

Table 7-4. Three-strategy development matrix. Each of the three strategies applies the same parameter configuration that combines the base scenario of Policy 1, Policy 2, and Policy 3; however, they have differing introduction times (A) and policy development rates (B).

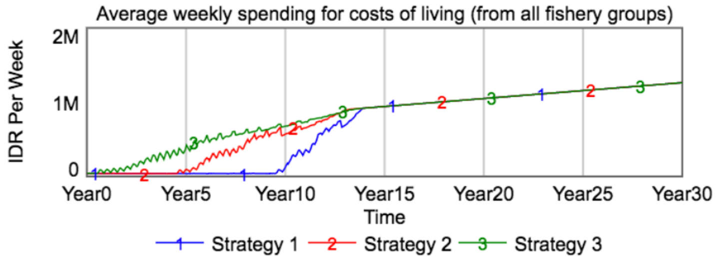
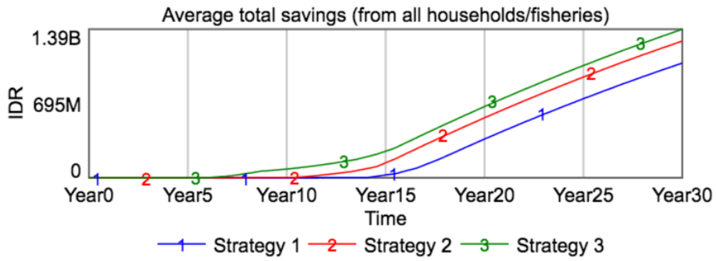
No.	Policy parameter under management control	Strategy 1	Strategy 2	Strategy 3
A	Introduction time:	Very late	Late	Early
1.	Year strategy introduced	Year 10	Year 5	Year 1
B	Policy development rate:	Rapid	Moderate	Slow
2.a	Period of policy introduction (Policy 1)	5 years	10 years	15 years
2.b	Period of policy introduction (Policy 2)	1 year	2.5 years	5 years
2.c	Period of policy introduction (Policy 3)	1 year	2.5 years	5 years

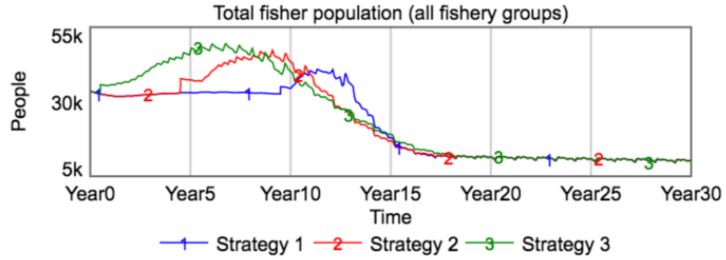
In the strategy variations (Table 7-4), the earliest policy introduction was paired with the slowest policy development rate and vice versa, which was intended to explore the trade-off between the two aspects in terms of any potential difference promoting the desired system behaviour relative to the base case model outcomes. This intention was concerned with the multiple objectives that the strategy would deliver in the real-world mainly of securing social welfare and, at the same time, ecological wealth. Due to the nature of this trait, its implementation process may manifest itself as a complex problem in its own right that can hinder the efficacy of the strategy. For example, conflicts among the implementing parties may arise as each of the policy components are being managed by different agencies/organisations (Fisher et al. 2017). Also, in the shorter term, the goals or outcomes during strategy implementation may involve temporary trade-offs that conflict with the expectations or objectives of a subset of the stakeholders affected by the strategy (Hoshino et al. 2017). Therefore, there is a future uncertainty regarding the policy stakeholder's capacity to fulfil collaborative management principles and practices (i.e., discussion in Section 2.3.2), which is demonstrably essential to achieving multiple objectives (e.g., in fisheries and marine resource management: Jupiter et al. (2014); Pomeroy, Katon and Harkes (2001)). Although local co-management successes in Indonesia have been documented (e.g., Campbell et al. (2013)), systemic barriers exist within Indonesia's formal governance mechanisms leading to compromised efforts with regards to larger-scale co-management practices, such as cross-institutional collaboration, resource-users' participation (e.g., due to corruption, powerful interest groups, overlapping authority and weak law enforcement: Brockhaus, Di Gregorio and Mardiah (2014); Enrici and Hubacek (2016); Korhonen-Kurki et al. (2013)), which are pivotal to the success of a multi-objective strategy.

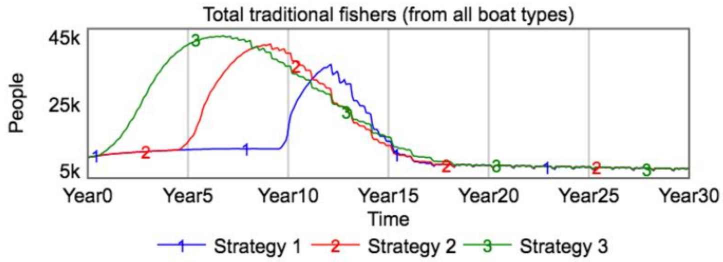
7.2.2 Results and analysis of the three strategies

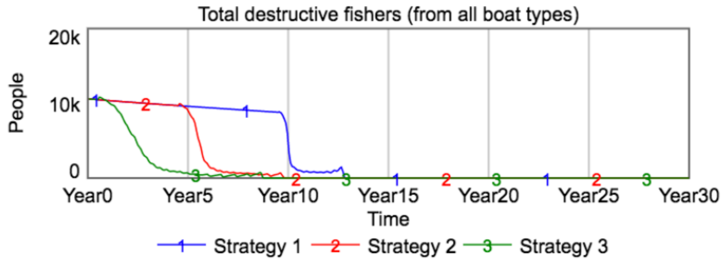
In general, all three strategies approach dynamic equilibrium states that are socially and ecologically desirable, while avoiding a series of problematic trends embedded in the base case. After 15 years, fishing households should be able to cover the costs of living above poverty thresholds, while maintaining household savings and avoiding the base case deficit and debt risks (no. 1, Table 7-5). Despite the fact that the number of total fishers would be lower than that of the initial point of time (no. 2, Table 7-5), the weekly profit earned by the fishing household breadwinner would improve significantly. This gain applies to the traditional groups (the first three charts of no. 3, showing the highest average [n=2 group, EN, NEN], Table 7-5) and, not surprisingly, destructive fishing would render the lowest profit rate due to restricted effort (last three charts of no. 3, Table 7-5). Similar to the individual policy test, this gain was relatable to the projected increase of local fish price rate due to the improving demand (no. 4, shown only from the predatory fish group). Parallel to the economic performances, the adult population of all three fish groups will eventually stabilise at a level lower than that of the initial stock (predatory), or, on par with the habitat's carrying capacity (herbivorous and squid/fast-reproducing) (no. 5, Table 7-5) since destructive fishing impact will be suppressed.

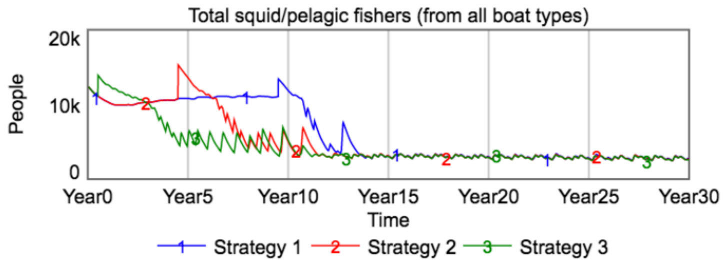
Table 7-5. Comparative line graphs showing output behaviour of the state variables under Strategies 1, 2, and 3.

No.	Comparative line graphs of the simulation outputs	Behaviour description
1.	 **A.**  **B.**  **C.**  **D.**	All three strategy variations would similarly increase weekly spending for costs of living (A), total savings (B), and reduce episodes of deficits (C), and debt (D) of the households on average.

<table>
<tr><th>No.</th><th>Comparative line graphs of the simulation outputs</th><th>Behaviour description</th></tr>
<tr><td>2.</td><td>


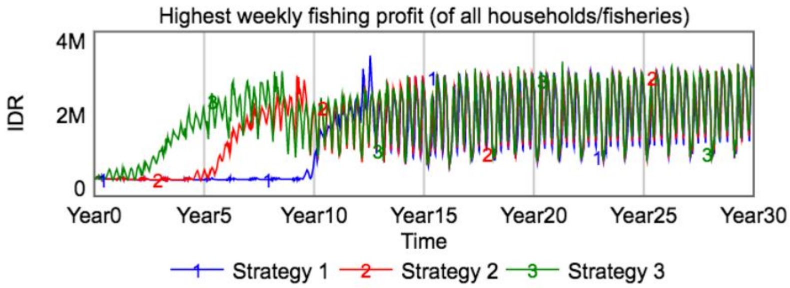
A.


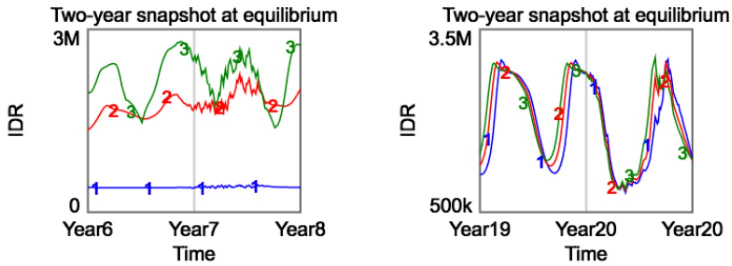
B.


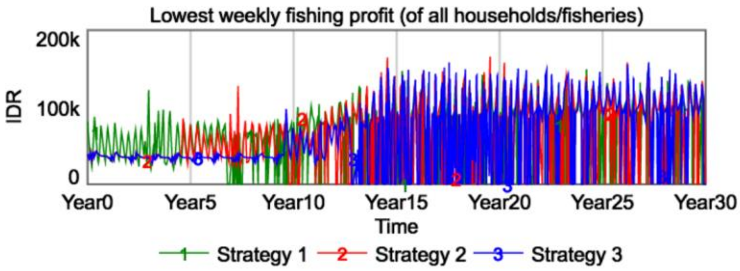
C.


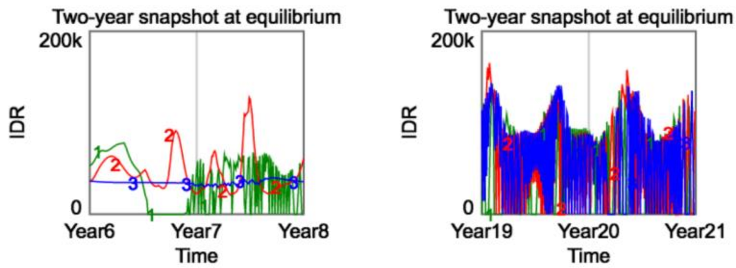
D.
</td><td>Under each of the three strategies, the total number of fishers in the community (A) and in each of the three fishery groups (B, C, & D) will be reduced.

After year 15, the total number of fishers of the traditional and squid/pelagic populations would be maintained at a level lower than that of the initial condition (2016), and zeroed for the destructive group.</td></tr>
</table>

<table>
<tr><th>No.</th><th>Comparative line graphs of the simulation outputs</th><th>Behaviour description</th></tr>
<tr><td>3.</td><td>


A.


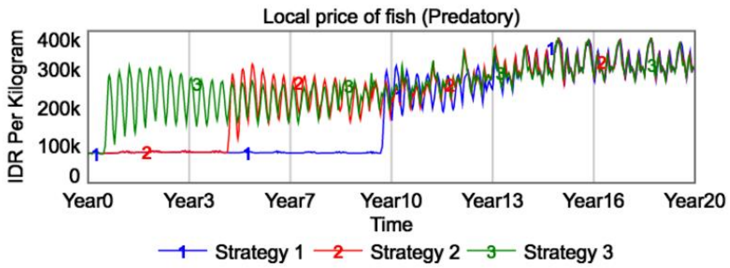
B.


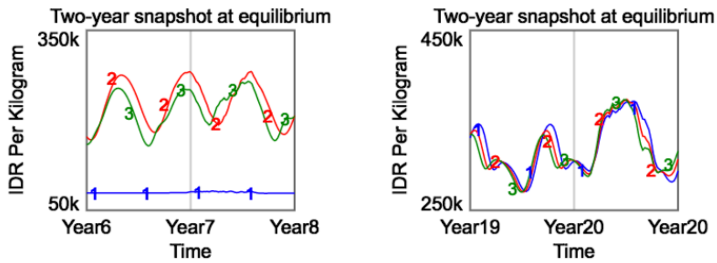
C.


D.
</td><td>Under all strategies, the highest average weekly fishing profit will increase and be maintained at an overall higher range of fluctuation than that of the initial level (A).

Fluctuations of the highest average weekly fishing profit will occur during the policy development before year 15 (B, left), and the full implementation after year 15 (B, right).

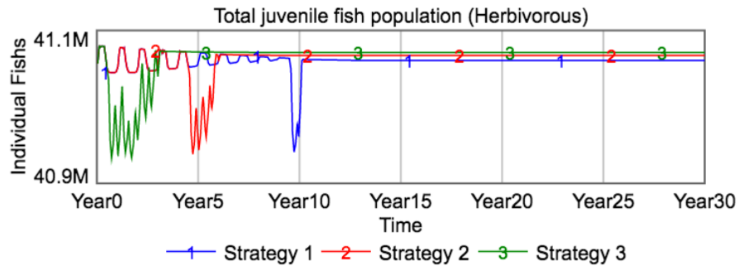
Episodes of zero average weekly fishing profit would occur and increase under all three strategies, and will be experienced mainly by the destructive fishery group (C).

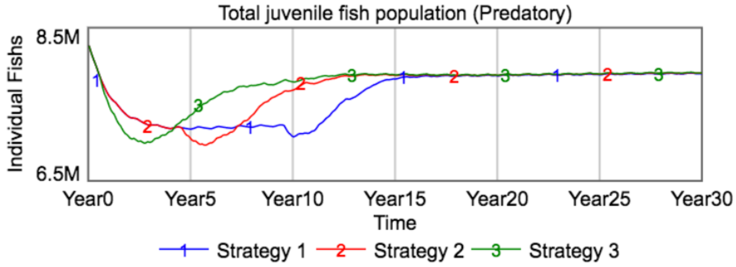
The null fishing profit of the destructive fishers will begin to occur before year 15 (D, left) and more frequently after year 15 (D, right), as depicted by the throughs at zero value in graphics.</td></tr>
<tr><td>4.</td><td>


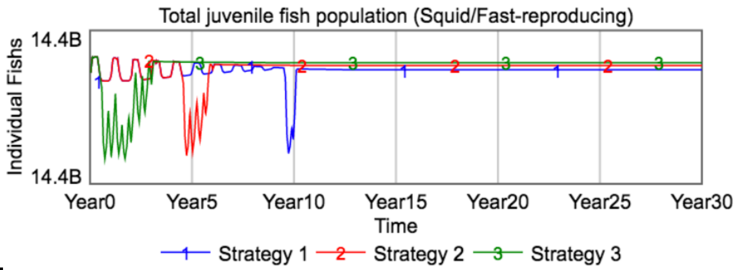
A.


B.
</td><td>All three strategies would eventually increase the local fish price of all fish classes (A, only the predatory fish class is shown as an example).

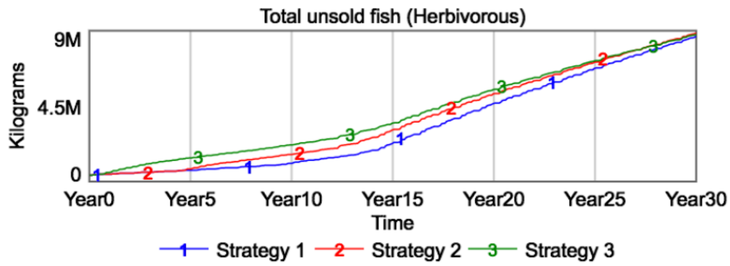
Fluctuations in fish price will occur during the strategy development before year 15 (B, left), and the full implementation after year 15 (B, right).</td></tr>
</table>

<table>
<tr><th>No.</th><th>Comparative line graphs of the simulation outputs</th><th>Behaviour description</th></tr>
<tr><td>5.</td><td>

A.


B.


C.</td><td>Under the three strategies, the juvenile and adult fish stock of the three fish classes will be sustained at the level of the carrying capacity of the habitats (A, B, & C; only the juvenile fish size-age group is shown as an example).

Fluctuations in fish price will occur during the strategy development before year 15 (B, left), and the full implementation after year 15 (B, right).</td></tr>
<tr><td>6.</td><td>
</td><td>All three strategies will increase the number of unsold fish, indicating a reoccurrence of local fish oversupply; this is a trend similar to that of the base case modelling results.</td></tr>
</table>

7.3 Outputs from scenario modelling

7.3.1 Scenario design and application

One of the limitations of the model developed here is that the estimation of the initial/baseline ecological parameters (e.g., fish habitat, fish population model) was justified by proxy information or data that was not from the Selayar region *per se*. This was due to the lack of relevant site-specific data at the time of this research, leading to the ‘loss’ of assumptions that may have been important to estimating the parameters. This likely means that the base case ecological parameters are inclined towards an average- or best-case (as opposed to ‘worst-case’) scenario.

In addition to uncertainties that could not be controlled, such as delays in the implementation of policies, there are also uncertainties that were introduced by the uncontrollable/external variables that are likely to vary socially and/or ecologically in the future. Also, it was understood that marine biophysical conditions and environmental change at a larger spatial scale have also contributed to the vulnerability of coastal communities and the maintenance of the social-ecological trap (Section 2.1.2, 2.1.3). Issues like climate change loom large as uncontrolled externalities. For this reason, the effectiveness of the Strategy (Section 7.2) under the climate change scenario was further explored. Following the modelling work of (Cheung et al. 2010), the scenario assumes that climate change would cause a shift in the fish distribution in the tropical areas, including Indonesia, which can lead to a reduction in the potential fish catch.

In order to understand the strategy in the context of climate change, a graphical converter was used to generate multiplier effect values representing the negative influence of climate change to the carrying capacity (CC) for both juvenile and adult fish. The influence was applied using five scenarios of linear reduction of total CC from all habitat. The reduction was set to start at year 0 with the multiplier value of 1 (i.e., no-adjustment) and end at year 30 with five scenario values of 0.95, 0.9, 0.85, 0.8, and 0.7 (i.e., CC already reduced for about 5 ~ 30% at year 30). The maximum CC reduction value of 30% was set as the 30-year equivalent of the maximum reduction of potential fish catch in the Indonesian region projected by (Cheung et al. 2010), which is up to 50% within a 50-year period. To explore the possible outcomes of ‘business-as-usual’ and ‘taking action’, each set of the five climate change scenarios are applied to the base case (henceforth, referred as ‘Simulation Set A’) and the Strategy 3 models (hence, referred to as ‘Simulation Set B’) using the parameter configuration described previously in Sections 6.2.2 and 7.2.1, respectively.

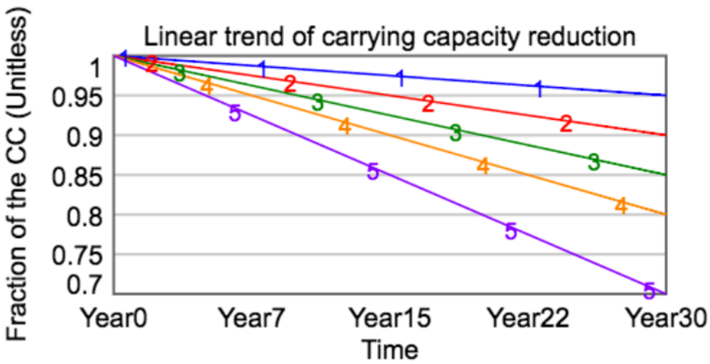


Figure 7-10. Fractional change of the carrying capacity applied in each of the five climate change scenarios (numbers).

7.3.2 Results and analysis of the scenario modelling

7.3.2.1 Simulation Set A: Base case model under climate change scenarios

Overall, from Simulation Set A, the problematic trends of the social and ecological state variables projected previously in Section 6.4.2 would be reproduced under all climate change scenarios. The rates of change increase in parallel to the increase in CC reduction which is shown, for example, in the projected decline of the adult fish population (Figure 7-11), and the highest average of weekly profit from fishing (Figure 7-12). The Simulation Setsuggests that, given the inevitable climate change (IPCC 2014b), there is a possibility that future trends in the vulnerability of the fishery-based livelihood in Selayar are greater than the estimated changes in our model.

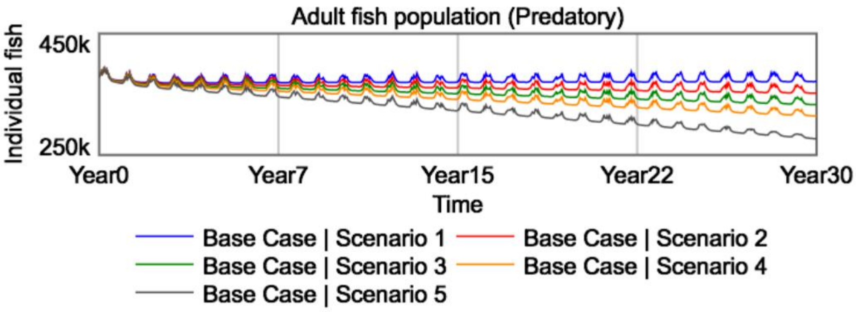


Figure 7-11. Projections of the adult fish population of the predatory group from Simulation Set A (base case model under five climate change scenarios).

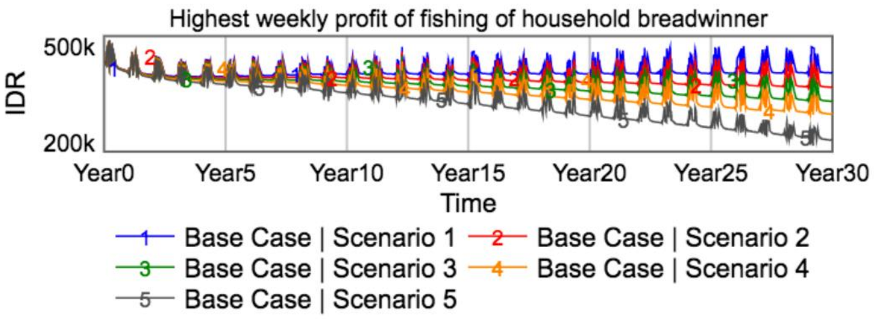


Figure 7-12. Projections of the highest average of weekly profit of fishing of the fishing household breadwinner from Simulation Set A (base case model under five climate change scenarios).

7.3.2.2 Simulation Set B: Strategy 3 implementation under climate change scenarios

On the other hand, based on the outputs of Simulation Set B, Strategy 3 would ultimately promote desirable equilibriums of the state of living variables under all of the five climate change scenarios, maintaining behaviours similar to those of the key outputs (no. 1) in Table 7-5. As the selected example demonstrates, these can also be identified from the average weekly spending on costs of living (Figure 7-13).

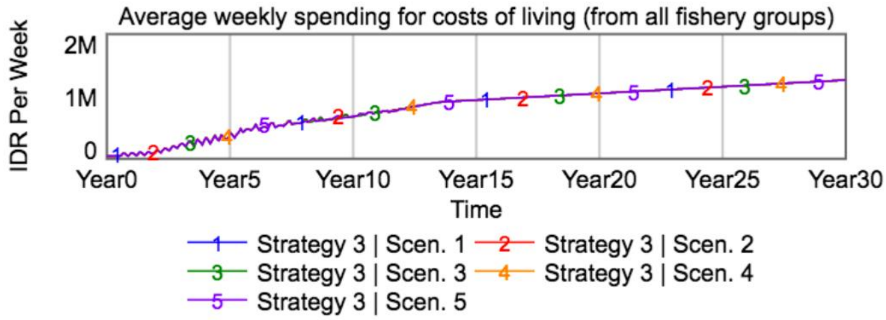


Figure 7-13. An example of the Strategy 3 output behaviours from the weekly spending on costs of living that represents the economic state of living of fishing households under five climate change scenarios.

However, parallel to the desired performance of the household financial state, under all five scenarios, the state of the natural resources would still decline. For example, this can also be seen from in the adult population of the herbivorous fish group (Figure 7-14). In this condition, the profitability of fishing will be affected. After year 15, under climate change scenarios 1, 2, and 3; the weekly fishing profit will fluctuate, maintaining peak levels that are higher than the initial condition; however, the through levels will be closer to those of the initial condition (Figure 7-15). Under scenarios 4 and 5, weekly fishing profit will fluctuate in a value range close, but still higher than, that of the initial condition (Figure 7-15).

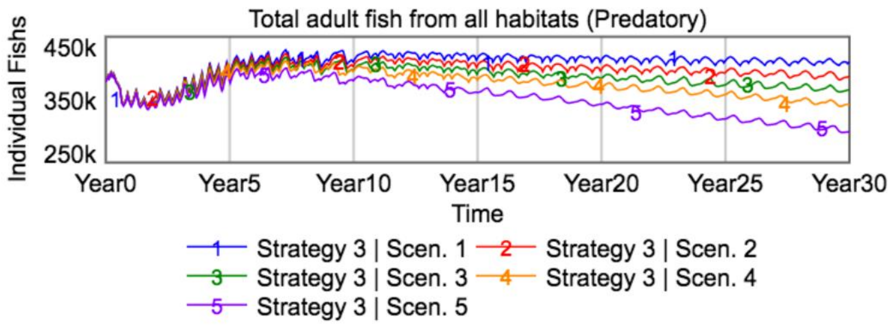


Figure 7-14. An example of the Strategy 3 output behaviours from one of the variables representing the fish resource under five climate change scenarios.

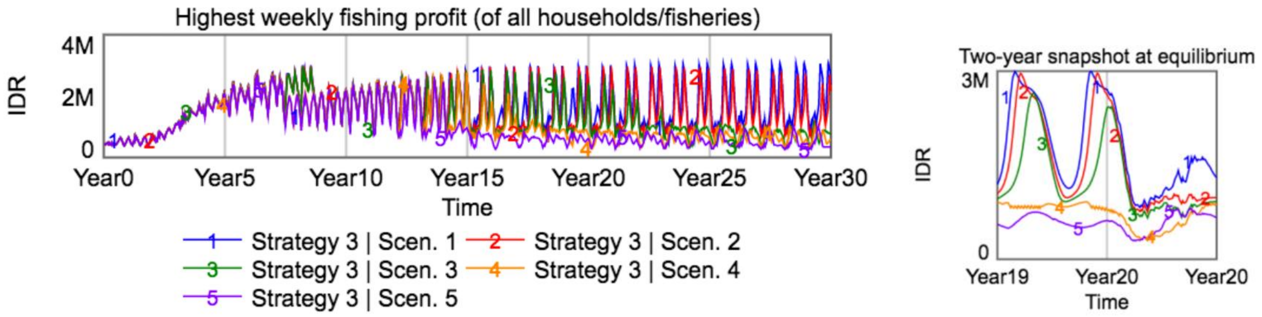


Figure 7-15. An example of the Strategy 3 output behaviours from the highest weekly profit of fishing that represents the economic state of living of fishing households under five climate change scenarios.

In general, this Simulation Set B suggests that Strategy 3 may become a viable precondition to enable Selayar fishing communities to better adapt to potentially inevitable livelihood changes, such as the decline in their marine fish production as well as fishery financial performance that would compound their pre-existing ‘declining reef fisheries’ problem.

7.4 Discussion

The findings in this chapter suggest that addressing the SES problem of *declining reef fisheries* in Indonesia requires multiple policies, each of which may deliver specific social, economic, and/or ecological interventions, and which are to be implemented simultaneously. Drawing from the modelling, the strategy (i.e., the combination of the three intervention policies) reduced the risk of undesirable outcomes and was fairly robust against the large uncertainties associated with the complex system models (Ferrol-Schulte et al. 2013; Fulton et al. 2011; Mahon, McConney & Roy 2008). Accordingly, these assessments have answered questions 2 and 3 of Main Assessment 3 of this research.

With respect to the outcome of the strategy variation (Section 7.2.2), interestingly, in spite of the sustained social-ecological improvement, there would still be unsold fish catch over the period (no. 6, showing only the highest form herbivorous group, Table 7-5). This finding raises the question as to whether local fishers will maintain their fishing effort when they recognise that there is a local oversupply of fish (i.e., unsold fish) despite the fact that their households are already in a better financial condition (i.e., no longer in a state of poverty). Under real-world conditions, the increase of financial capacity (e.g., net income, no. 1, Table 7-5) is one of the factors that can further increase the wants that people pursue (Witt 2001). Therefore, household savings/income can positively influence the expected costs of living in fishing households in Selayar. At the same time, under a developed marketing capacity (i.e., Policy 3: the unsold fish may not necessarily be wasted as unpurchased product may create a new demand for fish within (e.g., as food input for the local non-fishing population, animal farming, or tourism industry) or outside Selayar (e.g., export of low-value fish for aquaculture feed in other countries (Edwards, Tuan & Allan 2004)). Therefore, with the additional possibilities that local living standards will increase and new fish demand will emerge and continue to grow, a reduction of fishing effort may not take place in future despite the surplus of fish (i.e., unsold fish). Yet, these factors and relationships were not identified in this research or represented in the model.

On the other hand, both the fishery resources and fishing activities in the Selayar waters are very likely to be much more complex than those that were represented in the model (Österblom et al. 2013). The frequency, amount, and diversity of the harvested fish may be greater than that of the simulation results since additional fishing impacts from traditional fishers outside the boundary of Selayar and Gusung Pasi islands, including those with larger semi-commercial boats, are excluded from the modelling of both the problem and policies. Therefore, with the additional possibility that the actual carrying capacity of the fish habitats is lower than that of the model parameter, the accumulation of unsold fish (as described in the previous paragraph) also evokes caution that the rate of fish exploitation could be higher in the future and may negatively affect fish populations across various life-history stages (e.g., harvesting adult as well as juvenile fish) and trophic levels (e.g., fishing down the food web (Pauly et al. 1998)). However, these influences were not considered in the models developed and explored here.

Accordingly, in implementing the strategy, it is critical that the socio-economic improvement of local livelihoods also contributes to the process of building resource stakeholders' awareness of the ecosystem changes (Cundill & Rodela 2012). Under the livelihood condition in which scarcity of resources is no longer the predominant requirement and a general level of economic well-being has been achieved (i.e., the strategy model), it is assumed that resource users would have better capability to participate directly in the assessment and management of the natural resources. For example, fishers are also actively involved in a long-term data collection activity for time-series monitoring of the fish conditions, both during and outside of fishing. Hence, early-warning signals that the natural resource is being overharvested or heading towards collapse can be acknowledged (e.g., Carpenter et al. (2011)). Without a knowledge-based incentive – at the least – that can promote a collective effort to avoid the ecological risks, under the strategy scenario, harvesting by the remaining fishers may produce another episode of fish overexploitation in the longer term.

The strategy modelling results (Section 7.2.2) also suggest that varying the introduction year and implementation period of the strategy would not generally produce a noticeable difference in the level or dynamics of the state variables' stable equilibria (i.e., projection after around year 15, Table 7-5). This may suggest that the timing of the adjustment of the strategy-affected parameters is less influential than the magnitude of the adjustment (i.e., the level of profit of the non-fishing work, the maximum multiplier effect values of surveillance index change and demand increase) in order to strengthen the reinforcing feedbacks (e.g., Policy 1 for enhancing non-fishing work outputs in loop R14, Section 5.6.3.8) or weaken the reinforcing feedbacks (e.g., Policy 2 for demotivating destructive fishing in loop R2, R3, R4, Section 5.6.3.4; and Policy 3 for addressing fish price deflation in loop R5-A, R5-B, Section 5.6.3.3) that move the system towards an overall desirable state equilibrium (i.e., away from the trap, BOTG: Figure 5-56, discussion: Section 5.6.4.5). The importance of the problem intervention's magnitude also demonstrates the difficulty of 'breaking' down the social-ecological trap that authors have suggested (e.g., Platt (1973)), since the efficacy of the proposed solutions for trap situations (such as the strategy) predominantly demands a continual influence of 'counter-reinforcers' originating mainly external to the system (i.e., as an 'outside help') against the internal self-reinforcing feedback (i.e., underlying the path-dependency, Section 5.6.4.5) (Platt 1973). Although there is an opportunity for exploring the impact of strategy parameters variations further, due to the lack of site-specific data that can robustly justify a variation of policy parameters this was not done here.

In general, adding to the feedback mechanisms identified in Chapter 5, both dynamic modelling assessments (Chapters 6 and 7) were also able to capture the surrogates for system resilience through alternative trajectories of system state (i.e., path-dependence that can either lead to maladaptation [base case model] and/or the adaptation options inherent in the strategy model [Section 5.6.4.5]) and the opportunity for innovation (i.e., the proposed policies necessary for the desired system transformation). The modelling outcomes of this chapter have shown how working with a combination of leverage points (Meadows 1999) such as incentives (i.e., financial, as in Policy 1), constraints (i.e., through resource use restrictions, as in Policy 2), and gains (i.e., state of living as in Policy 1, and financial as in Policy 3) can potentially introduce new processes (i.e., feedbacks that reinforce household income and balance fishing intensification and habitat degradation) that move the livelihood system away from a basin of attraction delineated by thresholds of a deprived state (i.e., improving welfare state of the resource users and the condition of natural resources).

Furthermore, although the adjustment of livelihood parameters here was largely gradual, the projected livelihood transformation (e.g., from fishing-dependent households [Regime 1] to those with diversified enterprises [Regime 2]) almost entirely involved abrupt, simultaneous, and nonlinear system response behaviours. Parallel to this dynamic, from the comparison of the base case and the strategy output, each of the projected state transformations (i.e., the state variables) had its own bifurcation points that emerged relatively early (relative to the time horizon) after policies were introduced. This outcome also depicts the avoidance of the previously-conceptualised system maladaption (i.e., Section 5.6.4.5). These points are shown in Figure 7-16 using selected variables as examples.

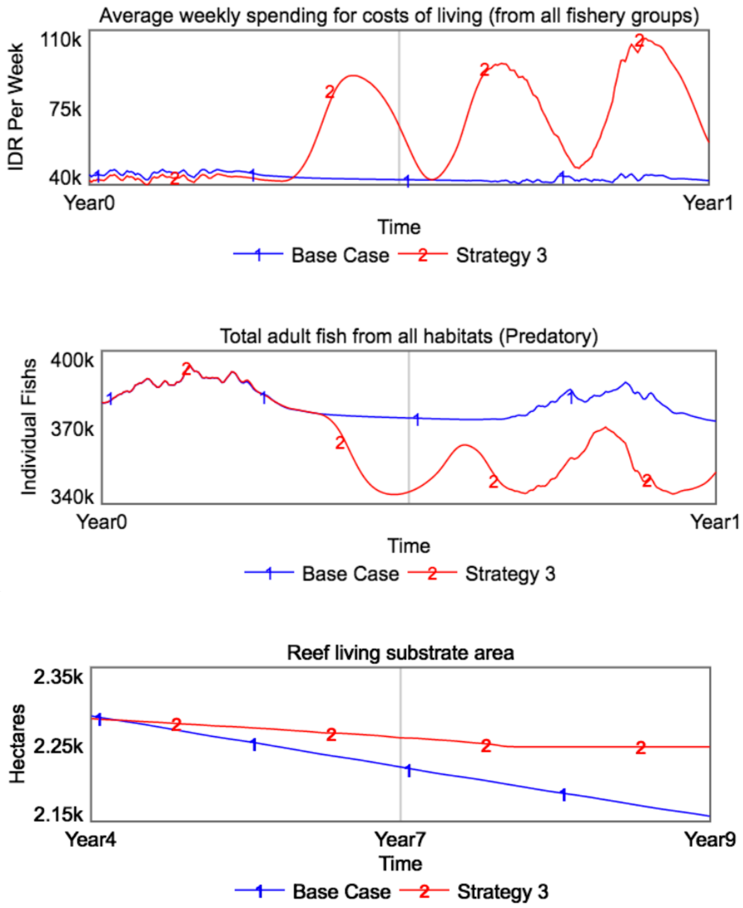


Figure 7-16. The bifurcation phase that was drawn from the comparison of the base case and the Strategy 3 outputs of the cost of living fulfilment, fish population, and fish habitat area.

In addition, the projections presented here also indicate that the observed nonlinear system change occurs at the same time the policy progresses. As discussed earlier, the strategy tests also suggest that the efficacy of the proposed strategy may be determined more by policy performance than implementation timing. These results suggest that the capacity of stakeholders to recognise a system's nonlinear response to the policies may be pivotal to understanding whether the policy is working or not, particularly for long-term policy implementation. For example, to know whether the measures that introduce supplementary income source to the fishing household would reduce the fisher's effort to harvest (Policy 1), one should track, among other things, the changes in household fishing activity and the productivity of the non-fishing livelihoods (Slater, Napigkit & Stead 2013).

Moreover, in relation to the necessity for collaboration in implementing the strategy (Section 7.2.1) the awareness of social nonlinearity factors, such as the power dynamics between stakeholders of different interests, may also help identify or avoid negative feedback from dominant parties that enforce decisions that can block or undermine the policy consensus (Adger, Brown & Tompkins 2006; Ito, Rachman & Savitri 2014). Yet, as demonstrated in the development of this research, nonlinearity within the Selayar fishery is attributable to the vast number of interacting variables that are not entirely able to be monitored by the problem stakeholders. With this need to embrace change and uncertainty in mind, the efficacy of the proposed strategy may warrant a novel governance and institutional process, such as the adaptive co-management discussed in Section 2.3.

In relation to the adaptive cycle (Section 2.2.8), the modelling outcomes also generally suggest that the maintenance the current livelihood constructs (i.e., base case model) would bring the system that is possibly manifesting into *conservation* phase. This phase can be indicated, for example, by the projected slowing-down of fish recovery, income stability (under poverty), sustained fluctuation of fish price, and low internal potential to adapt to change (e.g., lack of livelihood asset) despite high connectedness (e.g., informal local fishery groups). After this phase, the *creative destruction* phase follows, which is relatable to the model outcomes such as the persisting household financial problems (e.g., accumulation of debt and frequent deficits) and collapsing fishery (e.g., fishing operations becoming unprofitable).

On the other hand, if the desired system manipulations are exercised (i.e., the strategies), the creative destruction can hopefully be shortened or avoided. The outcome of the strategy model suggests that the livelihood system can move more rapidly (i.e., within 1 year) to the *reorganisation* phase, which is also depicted by the bifurcation phase (Figure 7-16). However, this transformation may be slower in the real world due to the possible management setback related to problems in large-scale stakeholder collaboration discussed earlier. In addition, the nature of management activities related to the strategy may require and introduce novel norms, ideas, and/or products that may be contradictory to current livelihood practices or other social behaviours. Therefore, there are also delays in livelihood transformation that may warrant the adaptation to intervention by the problem stakeholder (e.g., in Policy 1: due to the introduction of alternative occupation (Cinner & Bodin 2010; Fröcklin, Jiddawi & de la Torre-Castro 2018); in Policy 2: due to community-based surveillance and enforcement (O'Shea & Thompson 2006); and in Policy 3: due to marketing solutions (Adhuri et al. 2016)).

In summary, the systems dynamics assessments (Chapters 6 and 7) have explored a range of possibilities involving nonlinear dynamic behaviours that ultimately contribute to multiple stable equilibria of the livelihood state variables. It also demonstrates that the shift from equilibria that maintains a maladaptive livelihood regime to an alternative regime of proper adaptation is amenable through the proposed management actions (Chapter 7). However, although the approximation of the shift can be identified by the distance of the state variables from the thresholds for undesirable or desirable social/ecological conditions, the parameter and output values of the simulation are not reliable as a reference for the exact threshold values that would be generated in the real world. This applies particularly when model users want to pinpoint the exact levels or rates of when the trajectory of a state variable will deviate from a set course (i.e., threshold crossing), perhaps as a system enters a new regime (e.g., when the fish population starts to recover, debt begins to decline, alternative occupation profit surpasses fishing profit rate). This limitation relates mainly to the 'generic' nature of the simulation model that uses aggregate values for defining the stocks, rates, and/or constants for the abstraction of large number of active objects (e.g., human population, household financial condition, fish population); as well as parameter estimates (e.g., ecological) that were largely derived from proxy information/data and/or hypothetical inferences (e.g., dimensionless multipliers, Appendix 23). Hence, areas of further research were identified, which are presented in the next chapter.

Chapter 8 Conclusion

The PhD research presented here has explored the problem of managing coastal and marine resources within human-dominated areas of marine conservation priority on Selayar Island, Indonesia. In achieving its aims, this research has demonstrated that small-scale rural livelihoods based on capture fisheries in Selayar are part of an inherently complex and dynamic social-ecological system. As a result, associated community livelihood problems are being influenced by the synergy between the dynamics originating from the social and economic domains as well as the coastal and marine resources. The major finding was confirmation that the social-ecological trap phenomena are responsible for the articulated problem of *declining reef fishery* on Selayar Island. To deliver the main problem-solving contribution of this research, the final stage of this research has tested a number of problem interventions for their potential to simultaneously improve the sustainability of the marine resource users' livelihoods and the ecological condition of the marine resources. Before arriving at this stage, there are key findings from the results generated from the main activities presented in Chapters 4 to 7, which have addressed the research questions under each of the three main assessments. These findings are presented in the first part of this chapter. The next part discusses the limitations of the research, along with opportunities for future study.

8.1 Key findings in response to the key research questions

8.1.1 Main Assessment 1: Conceptually modelling interactions within the social-ecological systems that drive livelihoods operating in the Selayar Islands Regency, South Sulawesi Indonesia

Main Assessment 1 will answer questions such as:

1. What are the current livelihood systems and marine ecosystems occurring within the study area and the problems experienced by the associated communities?
2. What are the socio-ecological system components within the study area and the interactions between these components?
3. How do interactions between the socio-ecological system components cause mismatches between local livelihood activity and natural resource management in the study area?

The research commenced with a 'problem-scoping' activity, which identified the central problem to be explored by the research plan of the thesis, as well as the scope of stakeholders associated with the problem. It involved a series of focus group discussions (FGDs) held in communities associated with fishing villages in the Selayar and Gusung Pasi Island region. These field surveys gathered knowledge about the types, status, and past trends of the resources and activities and the priority problems associated with their livelihoods. In undertaking the problem-scoping activity, the first research question (Main Assessment 1) becomes: “What are the current livelihood systems and marine ecosystems occurring with the study area and the problems experienced by the associated communities?”.

The problem-scoping activity revealed that the local fishing activities largely involved the use of artisanal methods, conducted in both inshore and offshore areas, targeting a diverse range of fish species, and intended both for subsistence and the small-scale economy. Price uncertainty, weather disruptions, habitat damage due to destructive fishing activity, and perceived competition in fishing with boats originating outside Selayar were all key pressures that reduced the economic performance of fishing by the households. As part of their coping strategy, some households engaged in a supplementary occupation; these were mostly agriculture-based and yet economically performing at lower levels than fishing. These conditions were occurring synergistically and were relatable to the identified priority problems associated with the condition of fishery resources and/or fishing occupations that has been declining over the past five to ten years. These findings brought the confidence to define the problem topic of this research we termed “declining reef fisheries”.

The second and third activities involved problem mapping and causal modelling, leading to the second and third research question of Main Assessment 1. These were: “What are the socio-ecological system components within the study area and the interactions between these components?” and “How do interactions between the socio-ecological system components cause mismatches between local livelihood activity and natural resource management in the study area?”. The problem mapping involved a series of FGDs of each for which group model-building activities were conducted in the fishing villages. It captured mental information of the variables related to: resources, activities, pressures, and decisions; the interactions between these variables; and the perceived past and future trends – all of which related to the problem topic. Based on this information and supplementary interviews with fishers (i.e., the fourth activity), a causal loop diagram (CLD) was developed as a visual model of the components and interactions that define the boundary of livelihood system pertinent to the topic problem.

The results of the causal modelling confirmed that the topic problem involved a complex social-ecological system which interacted with associated determining variables. The interaction involves both endogenously influencing variables linked to human (i.e., fisher), social (i.e., fishery groups), financial (i.e., fish price), physical (i.e., access to fishing or farming area), or ecological (i.e., marine and terrestrial livelihood resources) assets, as well as exogenously influencing variables (e.g., weather condition, access to market/fish buyer, regional costs of living, fish ecosystem condition, non-Selayar fishers). Multiple reciprocal interactions between these variables were also visually assessed based on the feedback loops in the CLD (loops in Section 5.6.3). The feedback analysis revealed that actors within the modelled livelihood system are maladaptively responding to undesirable social/ecological conditions, such as of declining fish catch, fish price deflation due to fish oversupply (e.g., loops in Section 5.5.3.3) and increasing household financial burden (e.g., loops in Section 5.5.3.7) by taking decisions that consequently compound or reintroduce undesirable social/ecological changes over time (Section 5.5.4).

This confirmed that a "social-ecological trap" (SET) existed which involved 'nested' internal system decisions that reinforced: (1) the recurrence of problem symptoms due to livelihood quick fixes that reintroduce unintended social/ecological consequences; (2) the discouragement of fundamental solutions due to over-reliance on fishing by households when coping with the undesirable conditions; (3) the precariousness of the fishery in advancing ecological collapse or impoverished livelihoods due to the incomprehension of the actors in dealing with social and/or ecological limits; and (4), the reduced output per fishing activity due to fish exhaustion caused by the collective acceleration of fishing by the fishery groups. The major implication of these for resource management in Selayar is that, in the absence of interventions that can provide socio-economic help to enable resource users to escape from the SET, the participation and compliance of users with current marine resource management instruments that are primarily based on restrictions to resource access (e.g., marine reserves) and fishing effort (e.g., fishing gear regulations) is challenging at best due to an increase in other problems.

8.1.2 Main Assessment 2: Modelling feedback interactions between key socio-ecological system components influencing the behaviour of local livelihood systems

Main Assessment 2 will answer the following questions:

1. What are the flows of material or information within the local socio-ecological system and how do these flows influence system dynamics? (Ch. 6).
2. What are the key ecological, social, and economic drivers that influence material and information flows and how do these drivers influence system dynamics? (Ch. 6).

To assist in learning about the dynamic behaviours conceptualised from the feedback structures identified in the causal model, the fifth activity involved the development of a system dynamics model. This phase of the research addressed the questions associated with Main Assessment 2: "What are the flows of material or information within local socio-ecological system and how do these flows influence system dynamics?" and "What are the key ecological, social, and economic drivers that influence material and information flows and how do these drivers influence system dynamics?" (Ch. 6).

To address these questions, a stock-and-flow computer simulation model comprising around 140 stocks, 660 flows (of inflows, outflows, and bi-flows), 520 constant value input converters, 810 equation converters, and 59 graphical input converters was used to empirically simulate the resilience of small-scale fishery (SSF) households in Selayar. The model simulates aggregate values that reflect 13 state variables and about 20 variables/relationships that are chiefly associated with the household-level financial state, community-level fishing activity, community-level fish population and its habitat condition. Resource-related variables were mainly arrayed with different categories of fish habitat (n=4) and fish (n=3); and of fishery groups (n=3); boat motor types (n=2), sex types (n=2), and labour-age groups (n=3) for the fishing/household-related variables. Model tests of unit consistency and integration, mass-balance, and extreme conditions demonstrated that the formulated model structure, equations, and parameters produced behaviours that conform with the perceived bounded rationality of the problem stakeholders (i.e., variable relationship polarity) captured in the causal model.

Despite the data-poor conditions in Selayar, a base case model for the socioeconomic parameters was successfully defined using ecological parameters that were largely estimates derived from the best-available proxy data/information reflecting local biophysical conditions, along with demography statistics and reanalysis of a recent (2016) household survey dataset. Simulation of the base case model revealed that the undesirable future dynamics of the livelihood state variables conceptualised from the feedback analysis could be manifested in the 30-year period following 2016.

Summarising the dynamic modelling, the 30-year base case projections revealed that coral reef and seagrass fish habitats, fish populations, and weekly potential catch of all fishery groups and boats are declining gradually; but (importantly), they are not at the point of collapse. But weekly household fishing profits are increasing gradually, not due to the increase in fish prices or local demand (sales), but rather, the increase in the households' weekly fishing hours. Although the average rate of fish landings has declined, episodes of fish oversupply persist and can trigger price depreciation over time; these are mainly due to the fish demand that is largely dependent on local population consumption (which is projected to decrease). Despite improving fishing profits, fishing is not profitable enough for all fisheries/households to satisfy the lowest standard of living, which is set to increase over time. Consequently, ongoing episodes of household deficits continue to trigger the recurrence of loan-taking, with the majority of the household debts remaining unresolved. In year 30, about a quarter of the fishers in year 0 are no longer in the fishery. Within the time horizon, the fishery is predicted to be sustained by the fishing household, albeit in an impoverished livelihood state. These findings suggest that fishing livelihoods in Selayar may currently be locked into a vulnerable livelihood state trajectory, or become locked in, in the future.. Also, the projected dynamics largely demonstrate the expected undesirable future trend perceived by the participating villagers in the problem-mapping FGDs.

8.1.3 Main Assessment 3: Simulation-aided evaluation of the resilience of the existing and the alternative livelihood configuration to future uncertainty

Main Assessment 3 will answer the following questions:

1. What characteristics of the socio-ecological system makes it undesirably or desirably resilient? (Chs. 5 & 6).
2. What intervention(s), undesirably or desirably, modify the resilience of the system? (Ch. 7).
3. How resistant will the systems be to potential future ecological/social disturbances that the system may experience? (Ch. 7).

As mentioned earlier, the findings from the qualitative and quantitative modelling demonstrate the resilience of the livelihood system through the fishing community's ability to cope with shocks (e.g., fish price deflation) or disturbances (e.g., storms, increasing cost of living, uncontrollable destructive activities) that are strongly associated with the resilience properties of CAS, such as diversity, (e.g., in terms of a diversified fishing strategy, fishery resource diversity, social group diversity), complex interactions, and feedback-maintained nonlinear dynamics. In addition, the interactions and dynamics also occur in multiple observational scales (e.g., individual: fisher; smaller-group: households; large group: fishing communities/groups, fish supply chain actors; ecological communities: population of fish, fish habitat; regional environment: weather conditions) both within and outside the modelled Selayar fishery system. Moreover, within the same scale of the community, for example, multiple levels of dynamics are also established involving slower-changing (e.g., loss of carrying capacity for fish in the habitats, increased allocation of labour hours in fishing, reduction of fishing profits) and faster-changing variables (e.g., weather disruption to fishing, physical impact of destructive fishing, fish price deflation, decision by households to take loans). However, in the real system, some of the rates of change have been monitored by the problem stakeholders (e.g., human demography dynamics) and the larger portion is not able to be monitored (e.g., the dynamics of fish price, fishing operations, fish harvest, fish population, fish habitats), which suggests that a maladaptive livelihood state (i.e., the "declining reef fishery" as a SET) persisted in the past is also contributed by the lack of community's ability to navigate uncertainty of the social/ecological changes, and hence, to cope with it. The Selayar fishery livelihood is, therefore, resilient in a way that is normatively undesirable considering that shocks and disturbance are likely to be absorbed; but the social actors' adaptive capacity is lacking. Thus, the causal modelling and base case dynamic modelling addresses the first question of Main Assessment 3: “What characteristics of the socio-ecological system make it undesirably or desirably resilient?”.

To deliver the overarching research objective of exploring potential interventions that, in particular, can help fishing communities in Selayar avoid or escape SET that would likely ‘‘lock’’ the livelihood into an undesirable state, several policies were proposed and also tested in the developed dynamic model. Three policies were proposed based on the perceived intervention variables (i.e., Decision variable group) identified in the problem mapping. The policies are mainly related to the improvement of the non-fishing livelihood of households (Policy 1), the surveillance and enforcement of the destructive fishery groups (Policy 2), and the marketing of fish landed locally in Selayar (Policy 3). The policy modelling addresses the second and third research questions of Main Assessment 3: “How will the proposed intervention(s), undesirably or desirably, modify the resilience of the SSF livelihood system?” (Ch. 7), and “How resilient will the systems to the potential ecological/social disturbances that the system can experience in future?” (Ch. 7).

From the individual modelling of the policies, the results of Policy 1 demonstrate that a 15-year gradual increase of additional income stream from non-fishing occupation, up to the level of that similar to the average profit of agriculture-based household livelihoods in Selayar, will help fishing households escape the poverty and debt trap and thus reduce the fishery labour force. However, relative to the base case, there is an ecological trade-off in the form of a higher total rate of fish extraction/fishing effort and persisting habitat degradation, which was due to the increase in average fishing effort of the remaining fishers and ongoing destructive fishing.

The results of Policy 2 find that a 100-fold gradual reduction of the number of fishers and catch effort of the destructive group (blast and cyanide fishing) to an almost zero level of destructive activity over a five-year period will help coral reef and seagrass to recuperate, and thus maintain the ecosystem’s carrying capacity for fish. However, there are socioeconomic trade-offs, mainly in terms of fishing intensification by other groups (e.g., in-shore traditional and the squid/pelagic), which would reintroduce local fish oversupply and deflate fish sale price as local fish trading remains oligopsonistic.

The results of Policy 3 show an improvement in local fish sales to a level that can continuously fulfil a ‘nationwide’ fish demand increase scenario – at a rate similar to the 2016 national inflation rate and include three annual fourfold demand peaks during holiday/religious seasons, which would mean avoiding a local fish oversupply. In this condition, fish prices are maintained at a higher level relative to the base case, hence driving improvement of the average ‘take home’ profit of each fisher. Interestingly, under a poverty threshold based on the household and statistical data of 2016 and fixed annual inflation rate, the costs of the minimum standard of living are not yet fulfilled by the households of all fishery groups, although that fishing income is improving. At the same time, ecological trade-offs similar to those under Policy 1 (i.e., fishing intensification and persisting destructive fishing) are produced.

In contrast to the results of individual policy tests, where the policies are applied as a combination (hence, ‘Strategy’ – the combination of all three policies), the aforementioned trade-offs are not reproduced; thus, the problematic trends that result under the base case model are able to be avoided. Further testing of the strategy under scenarios of climate change impact suggest that the policy combination is, however, helpful in at least sustaining the financial well-being of the fishing household despite an inevitable fishery performance loss due to a potential climate-induced fish catch reduction in the Indonesian region. From the systems resilience perspective, these findings illustrate that simultaneous leverage points are required to weaken the nested internal feedbacks that reinforce SET *vis-à-vis* the maladaptive decisions of actors that maintain the “declining reef fisheries problem”. It also demonstrates that each policy has consequences that would likely be unanticipated and unintended as the policy trade-offs mentioned above (e.g., depletion of fish, fishing intensification) tend to develop gradually or so slowly that the magnitude of the impact is not perceived until it has reached a critical level.

In overall, these findings suggest that the Selayar fishery management system should shift from single-objective (i.e., marine reserves to restricted resource user access) to multiple objectives management (i.e., biological, economic, and social objectives) considering that the expected outcome of the proposed strategy is to improve both natural resource conservation and local socioeconomic development. This also highlights the need for facilitating adaptive and collaborative management to ensure the efficacy of the strategy. In real-life practice, multiple-objective solutions require multiple perspectives and knowledge, and, therefore, multiple-partnerships such as those applied in the policy planning and implementation. Given the immense social/ecological livelihood components that are not considered in the model and which may not be measurable in real life, it is worthwhile considering whether the livelihood system will respond accordingly to the expected social/ecological policy outcomes. Collaboration is, therefore, also critical to ensuring that problem stakeholders are able to adapt to the uncertain system response toward the policies. This could be achieved by, for example, by constantly testing and revising the policies over the course of their implementation, to ensure that ‘errors’ of potential undesirable social/ecological consequence are addressed.

8.2 Limitations and suggestions for future research

Several limitations were encountered in this study. Firstly, the overall scope of the study was limited to the study area of Selayar Island and focused on the livelihood activities associated with small-scale capture fisheries, within a range of analysis that was restricted to the assessment of community-level social changes and local-level ecological changes. Consequently, dynamic social/ecological phenomena that require analytical dimension at a higher (i.e., spatial: regional, global; temporal: beyond weekly basis) or lower (i.e., spatial: family, individual, patch of site; temporal: daily basis) scale, but influential to the focal problem (e.g., social: psychological decisions of actors, fishery economy at the regional or national scale; ecological: migration of fish population, physical-oceanographic conditions) were not assessed. Also, every SES is unique, and there is no panacea for the managing natural resource use (Ostrom & Cox 2010). Therefore, the identified pathways to maintaining or diminishing the livelihood-related problem may not be relevant to other livelihood activities (e.g., aquaculture, agriculture, non-natural-resource-based activities) occurring in Selayar or other areas. This limitation of the study scope provides a point of departure for future research, which is discussed in this section.

With the understanding that “every model is a representation of a system” (Sterman 2000), the causal and dynamic models developed in this research are fundamentally a simplification of the examined social-ecological system. The boundary of the represented system is restricted exclusively by the topic problem that frames the scope of this research. Mirroring the entire system is an impossibility and therefore many variables that occur in reality are excluded. Therefore, Sterman’s assertion that “all models are wrong”(2000), also applies to the models in this research.

However, as the problem-of-interest was not yet clearly defined at the beginning of our study, we commenced by eliciting and mapping the problem owners’ mental model to identify as practically as possible the key elements that can conceptualise the problematic system. Although the causal model, interview extracts, and notes of participant comments were able to capture a diverse set of variables, conditions, and/or processes contributing to the problem (Table 5-5, Chapter 5), many of these elements were omitted from the quantitative model development. Omissions of this kind were intentionally made, mainly on account of the absence of information that would justify the model parameter and/or the stock-and-flow structure, and to avoid an overly detailed model designed primarily for high-level abstraction of the system and macro-level problem analysis. These omissions constitute the inherent limitations of this research and at the same time suggest areas of focus for future research.

In relation to the problem stakeholder, the articulated topic problem was largely considered from the perspective of the ‘fish producers’ within the Selayar SSF. Yet, the problem scoping also found the topic problem to be associated with stakeholders other than the village community members who participated in this research. At the same time, the efficacy of the proposed problem interventions (i.e., the strategies, Chapter 7) requires a collaborative, learning-by-doing process for its long-term implementation process. Yet, at this stage of the research, the stakeholders' consensus on the problem model is still partial the stakeholders other than the participants of the FGDs (e.g., actors in the broader fishery supply chain and in the fishery management) does not yet have the same comprehension of the livelihood problem. Considering that learning and shared understanding is critical to bridge collaboration and problem solving (Berkes, F. 2009), an interesting focus for future research would be to assess the mental model of the excluded stakeholders about the problem model. This particularly applies to the stakeholders pivotal to the development and/or implementation of the proposed policies. However, the specific objective of this research was to identify key social, economic, or ecological factors that can influence the efficacy of the proposed policies. For this purpose, the models produced from this research can be used as a tool to facilitate learning at a macro-level perspective. Afterwards, the improved problem model can be used as a seed to develop quantitative models, such as systems dynamics or agent-based modelling, which have a lower level of abstraction for practical application in the process of operationalising (i.e., planning and implementing) the proposed policies.

As regards the model boundary, the variables contained in the causal and dynamic models in this study are entirely representative of the aggregate conditions or processes found in the real-life system. This approach was taken mainly due to the macro-level nature of the topic problem (e.g., describing population level changes) and limited site-specific information/data reflecting the Selayar SSF livelihood system. Accordingly, many lower-level variables and relationships internal to the social and ecological subsystems of the livelihood were omitted from the models. For example, the community/population-level relationships represented in the dimensionless multipliers (i.e., graphical functions, in Appendix 23) of the dynamic model are largely hypothetical. This suggests the need for further research to more closely examine and measure the association between the socio-economic determinant and outcomes variables/process as listed in Table 8-1; which can be done quantitatively using statistical indicators (e.g., correlation, regression) or qualitatively (e.g., using social indicators: norms, belief, values).

Table 8-1. Pairs of determinants and outcomes variables/processes considered necessary for further investigation (for measure of association).

No.	Determinants	Socio-economic outcomes
1	The financial output of one type of fishing activity relative to the other.	The decision of fishers/households to shift from fishing activity to non-fishing livelihood activity.
2	The change in the surveillance and enforcement of destructive fishing.	The decision of fishers to engage in destructive fishing.
3	The change in the employment demand and profit of fishing.	The decision of labourers to engage in fishing, and the allocation of fishing effort.

No.	Determinants	Socio-economic outcomes
4	The socioeconomic benefit of one or more particular fishing ground/s.	The allocation of fishing effort for a particular fishing ground, and the decision of fishers to move from one fishing ground to another.
5	The changes in the supply of fish, and the demand for fish.	The price of fish.
6	The change in the price of fish.	The demand for fish.
7	The change in the ecological condition of the commodity fish species.	The potential catch per unit of fishing effort of the fishers.
8	The change in the ecological condition of the fish habitats.	The change in the ecological condition of the commodity fish species.
9	The deficit experiences by the households.	The adjustment of the standard of living of households, and their decisions to take loans.
10	The relative importance between financial obligations and goals of fishers/households.	The decisions associated with financial management by the fishers/households.
11	The change in tertiary education capacity of the households.	The decisions by a member of the fishing community/household members to emigrate.

Furthermore, the livelihood-related decisions (e.g., fishing effort, fisher movement) represented in the model are largely influenced by economic factors, mainly involving economic returns, price, demand, and market. Accordingly, further studies need to be carried out to assess the internal influence of the more-diverse non-economic (e.g., cultural, psychological, political) conditions such as norms, attitudes, goals, and political and institutional settings, which also influence actors' behaviour and decision-making in undertaking their livelihood. Moreover, the largest uncertainty in the model lies in the exogenous influences of the fishery resources. This relates to the fish population dynamics and fish habitat conditions that were simulated by relying on a generic model that, at the same time, parameterised using levels and rates predominantly based on *in situ* or *ex-situ* observations from areas outside the Selayar region. Bearing in mind again the role of actors external to the livelihood system (e.g., fishery managers, government agencies beyond Selayar's district level, and civil society organisations) in delivering the potential long-term and multiple-objective policies, including the strategy, the robustness of the decision-making tool (such as the presented models) is therefore critical. This means the model should be sufficiently evidence-based to be empirically usable, for example, to assess risks (i.e., livelihood vulnerability) – at least, or able to detect changes resulting from management experiments (i.e., the strategy) during its long-term implementation process. Accordingly, this study calls for a long-term, time-series ecosystem monitoring initiative in the Selayar region that investigates the changes associated with the fish species and fish habitat critical to the SSF.

The previously suggested social and ecological inquiries may require a data-intensive undertaking given the higher-resolution information that would contribute, at the least, in improving the depth and accuracy of the existing causal model and systems dynamics model. For this reason, after juxtaposing the model boundary with the literature review (Chapter 2) and the parameter data gaps, a list of multiple research topics worth pursuing to support the Selayar fishery management was developed, as shown in Table 8-2.

Table 8-2. Suggested topics of research based on the variables/conditions/processes that are influential to the SSF livelihood dynamics in Selayar, but which were excluded from the models, or Selayar-specific data or datasets.

No.	Social influences	Economic influences	Ecological influences
1	Knowledge and perception of the ecosystem.	Livelihood activities – other than small-scale capture fisheries – originating from Selayar (e.g., aquaculture, agriculture) and outside of Selayar (e.g., larger-scale commercial fishing operating in Selayar waters).	Ecological changes in the commodity fish species.
2	Perception, awareness of, and compliance with rules and regulations.	Non-monetary economic incentives.	Ecological changes of the fish habitat critical to the commodity fish.
3	Non-economic norms, attitudes, goals, and priorities of individuals, households, and/or communities	Innovation and technology in the fishery and non-fishing livelihoods.	Biogeochemical and physical changes of the environment influential to the ecology of the fish resources.
4	Social capacity to collaboratively learn and manage the livelihood and natural resource system.	Market dynamics of the local fishery in relation to fish supply, fish demand/trading, fish price/value.	Biogeochemical and physical changes in the environment influential to the local socio-economic activities.

The lack of site-specific data limited not only the abovementioned parameter estimation, but also testing of the projected model behaviours to determine whether they quantitatively correspond to the behaviour in the real system. For example, the absence of time-series statistical data related to both social and ecological state variables (i.e., stocks related to resource conditions and financial conditions) at the required scale of analysis (i.e., fish population, fishing community, fisher's households) were not allowing statistical measurement of the correspondence between the model output (i.e., the base case trend) and data (i.e., past trend) such as by using R-squared to measure how close the model output data was to the fitted regression line of the observation data. Also, with the exclusion of non-resource-user stakeholders discussed earlier, realistic policy-related data that can describe the lower- and upper bounds of the optimal parameter values (e.g., for Policy 1: the revenue of non-fishing that can realistically be achieved by the policy stakeholders), as well as of constraint values (e.g., for Policy 1: the costs of non-fishing that would actually incur) were not obtained or available from the stakeholders relevant to the policy. Accordingly, optimisation simulation methods to find the best parameters (e.g., constant values) for the policies were not applied. Hence, although the modelling has evaluated the three proposed policies for their potential outcome to alter the system behaviour, it did not identify the optimal value of the policy parameters that would lead to the desired change (e.g., maximising: fish population, household income, and fish sales; or minimising: destructive fishing effort) in the state variables stocks.

Another limitation of this research involves biases that were introduced both by the research participant and the researchers, which might have distorted or restricted information resulting in the misrepresentation of the reality in the model. Firstly, despite a compelling number of community members involved the group model building, bias during the focus group discussions (FGD) possibly occurred due to participant selection error, moderator personality bias, and dominance/shyness/acquaintance bias. With regards to the first cause, although participant groupings were established, and each was dedicated to an FGD session, several village members from other groups seldom attending FGD session where her/his group does not belong to. In terms of the second cause, the research team members assumed the role of facilitator on a rotational basis, which might have caused variation in the delivery of the FGD facilitation script. As for the latter, power dynamics and socio-cultural differences among the individuals were apparent and unavoidable within the same participant group. This situation, on some occasions, resulted in disproportionate participation (e.g., engaging in the dialogue) caused by discussion overdominance by one or several participants, shyness such as by the younger participants, or uncritical agreement due to relational influence of acquaintances.

Secondly, in addition to the dynamic model parameterisation, which in some cases has been based on qualitative assumptions (i.e., dimensionless parameters) and/or non-site-specific data (i.e., ecological parameters), the initial (i.e., prior to model tests) development and of stock-and-flow structure and the corresponding equations were heavily dependent on the logical reasoning, knowledge, and experience of the author and the three supervising systems dynamics modelers in the team (CS, RR, NS). Therefore, this 'bounded rationality' (Simon 1991) on the part of the modeller might have unconsciously triggered a group-think mechanism that introduced bias through, for example, an overly detailed or overly simplistic stock-and-flow structure. In recognising this limitation, any stakeholders that use the model should be able to evaluate as well as modify the model critically. As more robust and rigorous methodologies will address the social and ecological inquiries discussed earlier, the dynamic model structure and parameters can be improved accordingly. Therefore, the detailed stock-and-flow model structure and equations have been included in the appendices.

8.3 Research implications

This research has successfully demonstrated that the complexity and dynamics of coastal and marine social-ecological systems (CM-SES), particularly those that exist within a data-poor region, such as Selayar, are assessable. This study appears to be the first to involve mixed-method, transdisciplinary, and participatory approaches to understanding the 'wicked' nature of the fisheries problem (i.e., Jentoft and Chuenpagdee (2009)) in an Indonesian region under an SES lens. These approaches also demonstrated that, despite a data-deficient study site, one can still assess the dynamics of important system variables that contribute to the problem maintenance as well as those that estimate the behaviour of the system in response to particular proposed policies and strategies. The policy testing assessment, in particular, provides an important insight that solutions that are introduced to address well-being problems of the communities do not have to be segregated from that of the environment, and vice versa.

This work contributes to the application of social-ecological systems (SES) concepts through the use of systems thinking (ST) and systems dynamics (SD) methods, which allow an understanding of SES characteristics, such as complexity of the coupled human-nature systems, the reciprocal feedback loop and cross-scale dynamics between the sub-systems that have been expressed in SES literature (i.e., Chapter 2). To date, there have been few examples of the application of the SES concept to better understand SESs in marine conservation areas, particularly with regards to the Indonesian region. This research has demonstrated the importance of understanding these SES characteristics in both the creation and the resolution of livelihood and ecological problems, particularly those that are historically persistent.

This study also demonstrates the operationalisation of the resilience theory by utilising SD methods, such as causal loop diagramming and stock-flow modelling (Ford 2010). These methods explicitly captured elements of systems resilience, such as the feedback and cross-scale dynamics between sub-systems (Folke 2006), which indicates whether the observed CM-SES is resilient in an undesirable or desirable manner over a period of time. The use of these methods has helped in elucidating many explanatory pathways contributing to CM-SES problems by better understanding: what current livelihood systems are, the expected future livelihood systems, the range of drivers and perturbations that affect the behaviour of the system, trajectory changes within the livelihood system, and mechanisms and levers for desirable livelihood system changes. The methods have also facilitated a 'holistic' approach through exploring forms of interactions of many of social, economic, and ecological factors, including some cultural and political factors which are not well-understood or amenable to conventional research methods.

This research has also accommodated one of the key conditions for adaptive collaborative management concepts, mainly those of the ‘systems perspective’, ‘trust and openness among actors’, and ‘support for collaboration’ (i.e., Section 2.3.2) by employing the community-based systems dynamics to improve both the understanding and management of CM-SES, which is a multi-knowledge and multi-stakeholder system by nature (Leslie et al. 2015; Partelow 2015). This was allowed by the use of participatory assessment tools ,such as focus group discussions (FGD) and group model-building (GMB) sessions, which moved participants from being sources of information in a survey to being involved with identifying and describing problems as they view them, structuring the origins of the problematic system, and analysing the model and identifying solutions. The combination exploratory (e.g., SD methods) and participatory assessments (e.g., FGD & GMB) took part in facilitating shared learning among stakeholders of the complex problem and, at the same time, address the power asymmetry among the two predominant factors affecting the success of co-management (Armitage, Berkes & Doubleday 2007).

As regards the data-poor study area, the research provides critical information for the fisheries management stakeholders of Selayar Island, at the least, as a first step towards comprehending the importance of a long-term multiple-objective intervention such as the modelled strategies to address the declining reef fisheries problem. It is also expected that any stakeholders – from academia, government, civil society or business institutions – in general, can apply the lessons of this study to implementing modelled strategies to better align livelihood objectives and marine resource management objectives in Selayar.

The participatory, causal, and dynamic modelling methods presented in this thesis are applicable to the investigation of almost any problem or phenomena involving a human-nature relationship at any particular spatial or temporal scale of observation (Hovmand 2014; Jackson 2003; Sterman 2000). To allow the utilization of the dynamic model, the stock-and-flow model structure and the embedded Stella equations can be found in Appendix 18 to 26. Also, the SESAMME app used in this research can be found in https://ccres.net/, and it is one of the Systems Analysis tools developed and tested in the CCRES project.

List of References

Abson, DJ, Fischer, J, Leventon, J, Newig, J, Schomerus, T, Vilsmaier, U, von Wehrden, H, Abernethy, P, Ives, CD, Jager, NW & Lang, DJ 2017, 'Leverage points for sustainability transformation', Ambio, vol. 46, no. 1, pp. 30-9.

Adams, AJ, Dahlgren, CP, Kellison, GT, Kendall, MS, Layman, CA, Ley, JA, Nagelkerken, I & Serafy, JE 2006, 'Nursery function of tropical back-reef systems', Marine Ecology Progress Series, vol. 318, pp. 287-301.

Adger, WN, Brown, K & Tompkins, EL 2006, 'The political economy of cross-scale networks in resource co-management', Ecology and Society, vol. 10, no. 2, p. 9.

Adger, WN, Hughes, TP, Folke, C, Carpenter, SR & Rockstrom, J 2005, 'Social-ecological resilience to coastal disasters', Science, vol. 309, no. 5737, pp. 1036-9.

Adhuri, DS, Rachmawati, L, Sofyanto, H & Hamilton-Hart, N 2016, 'Green market for small people: markets and opportunities for upgrading in small-scale fisheries in Indonesia', Marine Policy, vol. 63, pp. 198-205.

Aghion, P, Dechezlepre̒tre, A, Hemous, D, Martin, R & Van Reenen J 2012, Carbon taxes, path dependency and directed technical change: evidence fro the auto industry., Centre for Economic Performance. London School of Economics and Political Science, London, Working Paper.

Agrawal, A 2003, 'Sustainable governance of common-pool resources: context, methods, and politics', Annual Review of Anthropology, vol. 32, no. 1, pp. 243-62.

Agrawal, A & Redford, K 2006, Poverty, development and biodiversity conservation: shooting in the dark?, Working Paper No. 26, The Wildlife Conservation Society.

Ahmed, M & Lorica, MH 2002, 'Improving developing country food security through aquaculture development—lessons from Asia', Food policy, vol. 27, no. 2, pp. 125-41.

Ainsworth, CH, Pitcher, TJ & Rotinsulu, C 2008, 'Evidence of fishery depletions and shifting cognitive baselines in Eastern Indonesia', Biological Conservation, vol. 141, no. 3, pp. 848-59.

Albin, S, Forrester, JW & Breierova, L 2001, Building a system dynamics model: part 1: conceptualization, MIT, June 30, 1997.

Allen, CR & Garmestani, AS 2015, Adaptive management of social-ecological systems, Springer, Dordrecht.

Allison, E & Ellis, F 2001, 'The livelihoods approach and management of small-scale fisheries', Marine Policy, vol. 25, no. 5, pp. 377-88.

Allison, E & Horemans, B 2006, 'Putting the principles of the sustainable livelihoods approach into fisheries development policy and practice', Marine Policy, vol. 30, no. 6, pp. 757-66.

Allison, HE & Hobbs, RJ 2004, 'Resilience, adaptive capacity, and the “lock-in trap” of the Western Australian agricultural region', Ecology and Society, vol. 9, no. 1, p. 3.

Amin, B, Ismail, A, Arshad, A, Yap, CK & Kamarudin, MS 2009, 'Anthropogenic impacts on heavy metal concentrations in the coastal sediments of Dumai, Indonesia', Environ Monit Assess, vol. 148, no. 1-4, pp. 291-305.

Anderies, JM 2015, 'Understanding the dynamics of sustainable social-ecological systems: human behavior, institutions, and regulatory feedback networks', Bull Math Biol, vol. 77, no. 2, pp. 259-80.

Anderies, JM, Janssen, MA & Ostrom, E 2004, 'A framework to analyze the robustness of social-ecological systems from an institutional perspective', Ecology and Society, vol. 9, no. 1, p. 18.

Angelstam, P, Andersson, K, Annerstedt, M, Axelsson, R, Elbakidze, M, Garrido, P, Grahn, P, Jonsson, KI, Pedersen, S, Schlyter, P, Skarback, E, Smith, M & Stjernquist, I 2013, 'Solving problems in social-ecological systems: definition, practice and barriers of transdisciplinary research', Ambio, vol. 42, no. 2, pp. 254-65.

Armitage, D, Béné, C, Charles, AT, Johnson, D & Allison, EH 2012, 'The interplay of well-being and resilience in applying a social-ecological perspective', Ecology and Society, vol. 17, no. 4.

Armitage, D, Berkes, F & Doubleday, N (eds) 2007, Adaptive co-management: collaboration, learning, and multi-level governance, University of British Columbia Press, Vancouver.

Armitage, D & Johnson, D 2006, 'Can resilience be reconciled with globalization and the increasingly complex conditions of resource degradation in Asian coastal regions?', Geography and Environmental Studies Faculty Publications, <http://scholars.wlu.ca/geog_faculty/5.>.

Armitage, D & Marschke, M 2013, 'Assessing the future of small-scale fishery systems in coastal Vietnam and the implications for policy', Environmental Science & Policy, vol. 27, pp. 184-94.

Armitage, D, Plummer, R, Berkes, F, Arthur, R, Charles, A, Davidson-Hunt, I, Diduck, A, Doubleday, N, Johnson, D & Marschke, M 2009, 'Adaptive co-management for social-ecological complexity', Frontiers in Ecology and the Environment, vol. 7, no. 2, pp. 95-102.

Aswani, S 2011, 'Socioecological approaches for combining ecosystem-based and customary management in Oceania', Journal of Marine Biology, 2011, pp. 1-13.

Aswani, S & Hamilton, RJ 2004, 'Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (Bolbometopon muricatum) in the Roviana Lagoon, Solomon Islands', Environmental Conservation, vol. 31, no. 1, pp. 69-83.

Bailey, C, Dwiponggo, A & Marahudin, F 1987, Indonesian marine capture fisheries, The International Center for Living Aquatic Resource Management, Manila, Phillipines ; Directorate General of Fisheries, and Marine Fisheries Institute, Ministry of Agriculture, Jakarta, Indonesia, Manila, Phillipines.

Bailey, C & Pomeroy, C 1996, 'Resource dependency and development options in coastal Southeast Asia', Society & Natural Resources, vol. 9, no. 2, pp. 191-9.

Ban, NC, Adams, VM, Almany, GR, Ban, S, Cinner, JE, McCook, LJ, Mills, M, Pressey, RL & White, A 2011, 'Designing, implementing and managing marine protected areas: emerging trends and opportunities for coral reef nations', Journal of Experimental Marine Biology and Ecology, vol. 408, no. 1-2, pp. 21-31.

Barlas, Y 1994, 'Model validation in system dynamics', paper presented to 1994 International System Dynamics Conference, System Dynamics Society, Stirling, Scotland (1994).

Basurto, X 2005, 'How locally designed access and use controls can prevent the tragedy of the commons in a Mexican small-scale fishing community', Society and Natural Resources, vol. 18, no. 7, pp. 643-59.

Bell, S & Morse, S 2010, 'Triple task method: systemic, reflective action research', Systemic Practice and Action Research, vol. 23, no. 6, pp. 443-52.

Bellwood, D & Choat, JH 1990, 'A functional analysis of grazing in parrotfishes (family Scaridae): the ecological implications', Environmental Biology of Fishes, vol. 28, p. 26.

Bellwood, D, Hoey, A, Ackerman, J & Depczynski, M 2006, 'Coral bleaching, reef fish community phase shifts and the resilience of coral reefs', Global Change Biology, vol. 12, no. 9, pp. 1587-94.

Béné, C & Friend, RM 2011, 'Poverty in small-scale fisheries: old issue, new analysis', Progress in Development Studies, vol. 11, no. 2, pp. 119-44.

Béné, C, Macfadyen, G & Allison, EH 2007, Increasing the contribution of small-scale fisheries to poverty alleviation and food security, FAO Fisheries Technical Paper No. 481, FAO, Rome.

Bennett, EM, Cumming, GS & Peterson, GD 2005, 'A systems model approach to determining resilience surrogates for case studies', Ecosystems, vol. 8, no. 8, pp. 945-57.

Berkes, F 1985, 'Fishermen and "the tragedy of the commons"', Environmental Conservation, vol. 12, no. 3, pp. 199-206.

Berkes, F 2007, 'Community-based conservation in a globalized world', Proc Natl Acad Sci U S A, vol. 104, no. 39, pp. 15188-93.

—— 2009, 'Evolution of co-management: role of knowledge generation, bridging organizations and social learning', J Environ Manage, vol. 90, no. 5, pp. 1692-702.

Berkes, F 2009, 'Indigenous ways of knowing and the study of environmental change', Journal of the Royal Society of New Zealand, vol. 39, no. 4, pp. 151-6.

Berkes, F 2015, Coasts for people: interdisciplinary approaches to coastal and marine resource management, Routledge, New York.

Berkes, F, Colding, J & Folke, C (eds) 2008, Navigating social-ecological systems : building resilience for complexity and change, Cambridge University Press, Cambridge.

Berkes, F, Folke, C & Colding, J (eds) 2000, Linking social and ecological systems: management practices and social mechanisms for building resilience, Cambridge University Press, Cambridge.

Berkes, F, Hughes, TP, Steneck, RS, Wilson, JA, Bellwood, DR, Crona, B, Folke, C, Gunderson, LH, Leslie, HM, Norberg, J, Nystrom, M, Olsson, P, Osterblom, H, Scheffer, M & Worm, B 2006, 'Ecology. Globalization, roving bandits, and marine resources', Science, vol. 311, no. 5767, pp. 1557-8.

Berkes, F & Seixas, C 2005, 'Building resilience in lagoon social-ecological systems: a local-level perspective', Ecosystems, vol. 8, no. 8, p. 9.

Berkes, F & Turner, NJ 2006, 'Knowledge, learning and the evolution of conservation practice for social-ecological system resilience', Human Ecology, vol. 34, no. 4, pp. 479-94.

Bhandari, PB 2013, 'Rural livelihood change? Household capital, community resources and livelihood transition', Journal of Rural Studies, vol. 32, pp. 126-36.

Biggs, R, Carpenter, SR & Brock, WA 2009, 'Turning back from the brink: detecting an impending regime shift in time to avert it', Proc Natl Acad Sci U S A, vol. 106, no. 3, pp. 826-31.

Biggs, R, Rhode, C, Archibald, S, Kunene, LM, Mutanga, SS, Nkuna, N, Ocholla, PO & Phadima, LJ 2015, 'Strategies for managing complex social-ecological systems in the face of uncertainty: examples from South Africa and beyond', Ecology and Society, vol. 20, no. 1, p. 52.

Binder, CR, Hinkel, J, Bots, PWG & Pahl-Wostl, C 2013, 'Comparison of frameworks for analyzing social-ecological systems', Ecology and Society, vol. 18, no. 4, pp. 26-44.

Boonstra, WJ & de Boer, FW 2014, 'The historical dynamics of social-ecological traps', Ambio, vol. 43, no. 3, pp. 260-74.

Boonstra, WJ & Hanh, TTH 2014, 'Adaptation to climate change as social–ecological trap: a case study of fishing and aquaculture in the Tam Giang Lagoon, Vietnam', Environment, Development and Sustainability, vol. 17, no. 6, p. 18.

Bos, JJ, Brown, RR & Farrelly, MA 2013, 'A design framework for creating social learning situations', Global Environmental Change, vol. 23, no. 2, pp. 398-412.

Bosch, OJH, King, CA, Herbohn, JL, Russell, IW & Smith, CS 2007, 'Getting the big picture in natural resource management —systems thinking as "method" for scientists, policy makers and other stakeholders', Systems Research and Behavioral Science, vol. 24, no. 2, pp. 217-32.

BPS 2014, Statistical Yearbook of Indonesia 2014, Publication Number: 07330.1406, BPS Catalog: 1101001, BPS - Statistics Indonesia, <http://www.bps.go.id/hasil_publikasi/SI_2014/index3.php?pub=Statistik%20Indonesia%202014>.

—— 2015, Kepulauan Selayar dalam Angka 2015 (= Selayar Islands in Figures 2015), Publication Number 73016.1502, Badan Pusat Statistik, Kabupaten Kepulauan Selayar (Statistics of Kepulauan Selayar Regency).

—— 2018, Kabupaten Kepulauan Selayar dalam Angka 2018 (= Kepulauan Selayar Regency in Figures 2018), Publication Number 73016.1502, Badan Pusat Statistik, Kabupaten Kepulauan Selayar (Statistics of Kepulauan Selayar Regency).

Brand, F & Jax, K 2007, 'Focusing the meaning (s) of resilience: resilience as a descriptive concept and a boundary object', Ecology and Society, vol. 12, no. 1, p. 23.

Brockhaus, M, Di Gregorio, M & Mardiah, S 2014, 'Governing the design of national REDD+: An analysis of the power of agency', Forest Policy and Economics, vol. 49, pp. 23-33.

Brown, BE & Suharsono 1990, 'Damage and recovery of coral reefs affected by El Niño related seawater warming in the Thousand Islands, Indonesia', Coral Reefs, vol. 8, no. 4, pp. 163-79.

Brown, DG, Page, S, Riolo, R, Zellner, M & Rand, W 2005, 'Path dependence and the validation of agent-based spatial models of land use', International Journal of Geographical Information Science, vol. 19, no. 2, pp. 153-74.

Brown, K, Tompkins, EL & Adger, WN 2002, Making waves:iIntegrating coastal conservation and development, Earthscan Publications Ltd, London.

Brugère, Cc, Holvoet, K & Allison, EH 2008, Livelihood diversification in coastal and inland fishing communities: misconceptions, evidence and implications for fisheries management, FAO/DFID, Rome, Working paper.

Buckley, W 2008, 'Society as a complex adaptive system', Emergence: Complexity and Organization, vol. 10, no. 3, p. 28.

Budowski, G 2009, 'Tourism and environmental conservation: conflict, Ccexistence, or symbiosis?', Environmental Conservation, vol. 3, no. 1, pp. 27-31.

Bueno, NP 2012, 'Assessing the resilience of small socio-ecological systems based on the dominant polarity of their feedback structure', System Dynamics Review, vol. 28, no. 4, pp. 351-60.

Burke, L, Bryant, D, Mcmanus, J & Spalding, M 2002, 'Reefs at risk', World Resources Institute, New York.

Bush, SR, Zwieten, PAMv, Visser, L, Dijk, Hv, Bosma, R, Boer, WFd & Verdegem, M 2010, 'Scenarios for resilient shrimp aquaculture in tropical coastal areas', Ecology and Society, vol. 15, no. 2, p. 15.

Butler, JRA, Suadnya, W, Puspadi, K, Sutaryono, Y, Wise, RM, Skewes, TD, Kirono, D, Bohensky, EL, Handayani, T, Habibi, P, Kisman, M, Suharto, I, Hanartani, Supartarningsih, S, Ripaldi, A, Fachry, A, Yanuartati, Y, Abbas, G, Duggan, K & Ash, A 2014, 'Framing the application of adaptation pathways for rural livelihoods and global change in eastern Indonesian islands', Global Environmental Change, vol. 28, pp. 368-82.

Campbell, J, Townsley, P, Whittingham, E, Ward, A, Viryak, S, Bunthoeun, S, Ponley, H, Dyna, E, Ly, N, Panha, P, Sony, C, Sopanha, C, Sophany, K, Mayonry, I, Sreymom, S & Chhin, N 2005, Understanding the factors that support or inhibit livelihood diversification in Coastal Cambodia. An output from DFID-funded research in Cambodia, IMM Ltd, Exeter, UK.

Campbell, SJ, Kartawijaya, T, Yulianto, I, Prasetia, R & Clifton, J 2013, 'Co-management approaches and incentives improve management effectiveness in the Karimunjawa National Park, Indonesia', Marine Policy, vol. 41, pp. 72-9.

Campbell, SJ, Mukminin, A, Kartawijaya, T, Huchery, C & Cinner, JE 2014, 'Changes in a coral reef fishery along a gradient of fishing pressure in an Indonesian marine protected area', Aquatic Conservation: Marine and Freshwater Ecosystems, vol. 24, no. 1, pp. 92-103.

Carpenter, S, Walker, B, Anderies, J & Abel, N 2001, 'From metaphor to measurement: resilience of what to what?', Ecosystems, vol. 4, no. 8, pp. 765-81.

Carpenter, SR & Brock, WA 2008, 'Adaptive capacity and traps', Ecology and Society, vol. 13, no. 2, p. 40.

Carpenter, SR, Cole, JJ, Pace, ML, Batt, R, Brock, WA, Cline, T, Coloso, J, Hodgson, JR, Kitchell, JF, Seekell, DA, Smith, L & Weidel, B 2011, 'Early warnings of regime shifts: a whole-ecosystem experiment', Science, vol. 332, no. 6033, pp. 1079-82.

Carpenter, SR, Mooney, HA, Agard, J, Capistrano, D, Defries, RS, Diaz, S, Dietz, T, Duraiappah, AK, Oteng-Yeboah, A, Pereira, HM, Perrings, C, Reid, WV, Sarukhan, J, Scholes, RJ & Whyte, A 2009, 'Science for managing ecosystem services: Beyond the millennium ecosystem assessment', Proc Natl Acad Sci U S A, vol. 106, no. 5, pp. 1305-12.

Carpenter, SR, Westley, F & Turner, MG 2005, 'Surrogates for resilience of social–ecological systems', Ecosystems, vol. 8, no. 8, pp. 941-4.

Cash, DW, Clark, WC, Alcock, F, Dickson, NM, Eckley, N, Guston, DH, Jager, J & Mitchell, RB 2003, 'Knowledge systems for sustainable development', Proc Natl Acad Sci U S A, vol. 100, no. 14, pp. 8086-91.

Cavana, RY 2010, 'Scenario modelling for managers: a system dynamics approach', in M Ehrgott & A Mason (eds), Proceedings of the 45th Annual Conference of the ORSNZ, Auckland, New Zealand, pp. 219-28.

Cavana, RY & Maani, KE 2000, 'A methodological framework for systems thinking and modelling (ST&M) interventions', in 1st International Conference on Systems Thinking in Management.

Cesar, H, Burke, L & Pet-Soede, L 2003, The Economics of Worldwide Coral Reef Degradation, Cesar Environmental Economics Consulting (CEEC), Arnhem, The Netherlands.

Chambers, R & Conway, GR 1992, Sustainable Rural Livelihoods: Practical Concepts for the 21st Century, 296, Institute of Development Studies, Brighton, 10 November 2014, <http://opendocs.ids.ac.uk/opendocs/handle/123456789/775#.VGBMTt4rmfR>.

Chang, YC, Hong, FW & Lee, MT 2008, 'A system dynamic based DSS for sustainable coral reef management in Kenting coastal zone, Taiwan', Ecological Modelling, vol. 211, no. 1-2, pp. 153-68.

Checkland, P 1981, Systems thinking, systems practice, J. Wiley & Sons, Chichester, New York.

—— 2000, 'Soft systems methodology: A thirty year retrospective', Systems Research and Behavioral Science, vol. 17, p. 48.

Checkland, P & Poulter, J 2006, Learning for action: a short definitive account of soft systems methodology and its use for practitioners, teachers, and students, John Wiley and Sons Ltd, Chichester.

—— 2010, 'Soft Systems Methodology', in M Reynolds & S Holwell (eds), Systems approaches to managing change: a practical guide, Springer-Verlag London Limited, pp. 191-242, DOI 10.1007/978-1-84882-809-4_5.

Chen, Y-F, Qi, J, Zhou, J-X, Li, Y-P & Xiao, J 2004, 'Dynamic modeling of a man–land system in response to environmental catastrophe', Human and Ecological Risk Assessment: An International Journal, vol. 10, no. 3, pp. 579-93.

Cheung, WWL, Lam, VWY, Sarmiento, JL, Kearney, K, Watson, REG, Zeller, D & Pauly, D 2010, 'Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change', Global Change Biology, vol. 16, no. 1, pp. 24-35.

Christie, P 2004, 'Marine protected areas as biological successes and social failures in Southeast Asia', American Fisheries Society Symposium, vol. 42, pp. 155-64.

CIA 2013, The World Factbook, Central Intelligence Agency, viewed 9 September 2013, <https://www.cia.gov/library/publications/the-world-factbook/geos/id.html>.

Cinner, J 2014, 'Coral reef livelihoods', Current Opinion in Environmental Sustainability, vol. 7, pp. 65-71.

Cinner, J, Fuentes, M & Randriamahazo, H 2009, 'Exploring social resilience in Madagascar's marine protected areas', Ecology and Society, vol. 41, no. 1, p. 41.

Cinner, J, Marnane, MJ, McClanahan, TR & Almany, GR 2006, 'Periodic closures as adaptive coral reef management in the Indo-Pacific', Ecology and Society, vol. 11, no. 1, p. 31.

Cinner, J, McClanahan, T, Wamukota, A, Darling, E, Humphries, A, Hicks, C, Huchery, C, Marshall, N, Hempson, T, Graham, N, Bodin, Or, Daw, T & Allison, E 2013, Social-ecological vulnerability of coral reef fisheries to climatic shocks, FAO, Rome.

Cinner, J & Pollnac, R 2004, 'Poverty, perceptions and planning: why socioeconomics matter in the management of Mexican reefs', Ocean and Coastal Management, vol. 47, no. 9-10, pp. 479-93.

Cinner, JE 2007, 'Designing marine reserves to reflect local socioeconomic conditions: lessons from long-enduring customary management systems', Coral Reefs, vol. 26, no. 4, pp. 1035-45.

—— 2010, 'Poverty and the use of destructive fishing gear near east African marine protected areas', Environmental Conservation, vol. 36, no. 04, pp. 321-6.

—— 2011, 'Social-ecological traps in reef fisheries', Global Environmental Change, vol. 21, no. 3, pp. 835-9.

Cinner, JE & Aswani, S 2007, 'Integrating customary management into marine conservation', Biological Conservation, vol. 140, no. 3-4, pp. 201-16.

Cinner, JE, Basurto, X, Fidelman, P, Kuange, J, Lahari, R & Mukminin, A 2012, 'Institutional designs of customary fisheries management arrangements in Indonesia, Papua New Guinea, and Mexico', Marine Policy, vol. 36, no. 1, pp. 278-85.

Cinner, JE & Bodin, O 2010, 'Livelihood diversification in tropical coastal communities: a network-based approach to analyzing 'livelihood landscapes'', PLoS One, vol. 5, no. 8, p. e11999.

Cinner, JE & David, G 2011, 'The human dimensions of coastal and marine ecosystems in the Western Indian Ocean', Coastal Management, vol. 39, no. 4, pp. 351-7.

Cinner, JE, Daw, T, Huchery, C, Thoya, P, Wamukota, A, Cedras, M & Abunge, C 2014, 'Winners and losers in marine conservation: fishers' displacement and livelihood benefits from marine reserves', Society & Natural Resources, vol. 27, no. 9, pp. 994-1005.

Cinner, JE, Daw, T & McClanahan, TR 2009, 'Socioeconomic factors that affect artisanal fishers' readiness to exit a declining fishery', Conserv Biol, vol. 23, no. 1, pp. 124-30.

Cinner, JE, Folke, C, Daw, T & Hicks, CC 2011, 'Responding to change: using scenarios to understand how socioeconomic factors may influence amplifying or dampening exploitation feedbacks among Tanzanian fishers', Global Environmental Change, vol. 21, no. 1, pp. 7-12.

Cinner, JE, Graham, NA, Huchery, C & Macneil, MA 2013, 'Global effects of local human population density and distance to markets on the condition of coral reef fisheries', Conservation Biology, vol. 27, no. 3, pp. 453-8.

Cinner, JE, McClanahan, TR, Daw, TM, Graham, NA, Maina, J, Wilson, SK & Hughes, TP 2009, 'Linking social and ecological systems to sustain coral reef fisheries', Current Biology, vol. 19, no. 3, pp. 206-12.

Clifton, J 2013, 'Refocusing conservation through a cultural lens: improving governance in the Wakatobi National Park, Indonesia', Marine Policy, vol. 41, pp. 80-6.

Costanza, R, d'Arge, R, de Groot, R, Farberk, S, Grasso, M, Hannon, B, Harin Limburg, Naeem, S, O'Neill, RV, Paruelo, J, Raskin, RG, Sutton, P & van den Belt, M 1997, 'The value of the world's ecosystem services and natural capital', Nature, vol. 387, p. 8.

Coulthard, S 2008, 'Adapting to environmental change in artisanal fisheries—insights from a South Indian lagoon', Global Environmental Change, vol. 18, no. 3, pp. 479-89.

Cramb, RA, Colfer, CJP, Dressler, W, Laungaramsri, P, Le, QT, Mulyoutami, E, Peluso, NL & Wadley, RL 2009, 'Swidden transformations and rural livelihoods in Southeast Asia', Human Ecology, vol. 37, no. 3, pp. 323-46.

Crawford, B, Siahainenia, A, Rotinsulu, C & Sukmara, A 2004, 'Compliance and enforcement of community-based coastal resource management regulations in North Sulawesi, Indonesia', Coastal Management, vol. 32, no. 1, pp. 39-50.

Creswell, JW 2014, Research design: qualitative, quantitative, and mixed methods approaches, vol. 4th, SAGE Publications, Thousand Oaks.

Creswell, JW & Plano Clark, VL 2011, Designing and conducting mixed methods research, vol. 2nd, SAGE Publications, Thousand Oaks.

Cullen, JJ, Franks, PJS, Karl, DM & Longhurst, A 2002, 'Phsyical influences on marine ecosystem dynamics', in AR Robinson, JJ McCarthy & BJ Rothschild (eds), The Sea, John Wiley & Sons, Inc., New York, vol. 12, pp. 297-336.

Cullen-Unsworth, LC, Nordlund, LM, Paddock, J, Baker, S, McKenzie, LJ & Unsworth, RK 2014, 'Seagrass meadows globally as a coupled social-ecological system: implications for human wellbeing', Mar Pollut Bull, vol. 83, no. 2, pp. 387-97.

Cumming, G, Barnes, G, Perz, S, Schmink, M, Sieving, K, Southworth, J, Binford, M, Holt, R, Stickler, C & Van Holt, T 2005, 'An exploratory framework for the empirical measurement of resilience', Ecosystems, vol. 8, no. 8, pp. 975-87.

Cumming, GS 2017, 'A review of social dilemmas and social-ecological traps in conservation and natural resource management', Conservation Letters, vol. 11, no. 1.

Cumming, GS & Peterson, GD 2017, 'Unifying research on social-ecological resilience and collapse', Trends in Ecology and Evolution, vol. 32, no. 9, pp. 695-713.

Cundill, G & Rodela, R 2012, 'A review of assertions about the processes and outcomes of social learning in natural resource management', Journal of environmental management, vol. 113, pp. 7-14.

Davis, A & Bailey, C 1996, 'Common in custom, uncommon in advantage: common property, local elites, and alternative approaches to fisheries management', Society & Natural Resources, vol. 9, no. 3, pp. 251-65.

Daw, TM, Cinner, JE, McClanahan, TR, Brown, K, Stead, SM, Graham, NA & Maina, J 2012, 'To fish or not to fish: factors at multiple scales affecting artisanal fishers' readiness to exit a declining fishery', PLoS One, vol. 7, no. 2, p. e31460.

De Vaus, D 2002, Surveys in social research, Allen & Unwin, Australia.

Derissen, S, Quaas, MF & Baumgärtner, S 2011, 'The relationship between resilience and sustainability of ecological-economic systems', Ecological Economics, vol. 70, no. 6, pp. 1121-8.

deYoung, B, Barange, M, Beaugrand, G, Harris, R, Perry, RI, Scheffer, M & Werner, F 2008, 'Regime shifts in marine ecosystems: detection, prediction and management', Trends in Ecology and Evolution, vol. 23, no. 7, pp. 402-9.

DKP Selayar 2014, Statistik perikanan tangkap Kabupaten Selayar lima tahun terakhir (= Selayar District capture fisheries statitstics in the last five years, Selayar.

Dudgeon, SR, Aronson, RB, Bruno, JF & Precht, WF 2010, 'Phase shifts and stable states on coral reefs', Marine Ecology Progress Series, vol. 413, pp. 201-16.

Edinger, EN, Jompa, J, Limmon, GV, Widjatmoko, W & Risk, MJ 1998, 'Reef degradation and coral biodiversity in Indonesia: effects of land-based pollution, destructive fishing practices and changes over time', Mar Pollut Bull, vol. 36, no. 8, pp. 617-30.

Edwards, P, Tuan, LA & Allan, GL 2004, A survey of marine trash fish and fish meal as aquaculture feed ingredients in Vietnam, Australian Centre for International Agricultural Research, Canberra, Australia.

Elliott, G, Wiltshire, B, Manan, IA & Wismer, S 2001, 'Community participation in marine protected area management: Wakatobi National Park, Sulawesi, Indonesia', Coastal Management, vol. 29, no. 4, pp. 295-316.

Enfors, E 2013, 'Social–ecological traps and transformations in dryland agro-ecosystems: using water system innovations to change the trajectory of development', Global Environmental Change, vol. 23, no. 1, pp. 51-60.

Eng, CT, Paw, JN & Guarin, FY 1989, 'The environmental impact of aquaculture and the effects of pollution on coastal aquaculture development in Southeast Asia', Mar Pollut Bull, vol. 20, no. 7, pp. 335-43.

Enrici, A & Hubacek, K 2016, 'Business as usual in Indonesia: governance factors effecting the acceleration of the deforestation rate after the introduction of REDD+', Energy, Ecology and Environment, vol. 1, no. 4, pp. 183-96.

Eriksson, HB, Osterblom, H, Crona, B, Troell, M, Andrew, NL, Wilen, J & Folke, C 2015, 'Contagious exploitation of marine resources', Frontiers in Ecology and the Environment, vol. 13, no. 8, pp. 435-440.

Evans, SM, Dawson, M, Day, J, Frid, CLJ, Gill, ME, Pattisina, LA & Porter, J 1995, 'Domestic waste and TBT pollution in coastal areas of Ambon Island (Eastern Indonesia)', Mar Pollut Bull, vol. 30, no. 2, pp. 109-15.

Fabricius, C & Cundill, G 2014, 'Learning in adaptive management: insights from published practice', Ecology and Society, vol. 19, no. 1., p. 29.

Fabricius, C & Currie, B 2015, 'Adaptive co-management', in CR Allen & AS Garmestani (eds), Adaptive management of social-ecological systems, Springer, Dordrecht, pp. 147-80.

Falkus, M 1990, 'Economic history and environment in Southeast Asia', Asian Studies Review, vol. 14, no. 1, pp. 65-79.

FAO 2004a, Report of the second session of the working party on small-scale fisheries - Bangkok, Thailand, 18 - 21 November 2003, FAO/Advisory Committee on Fisheries Research, <http://www.fao.org/docrep/006/y5245e/y5245e00.HTM>.

—— 2004b, The State of World Fisheries and Aquaculture 2004, FAO Fisheries and Aquaculture Department, Rome.

—— 2005, Increasing the contribution of small-scale fisheries to poverty alleviation and food security, FAO technical guidelines for responsible fisheries No.10, FAO, Rome.

—— 2014, The state of world fisheries and aquaculture 2014: opportunities and challenges, FAO Fisheries and Aquaculture Department, Rome.

—— 2016, The state of world fisheries and aquaculture 2016: Contributing to food security and nutrition for all, FAO Fisheries and Aquaculture Department, Rome.

Feeny, D, Hanna, S & McEvoy, AF 1996, 'Questioning the assumptions of the "tragedy of the commons" model of fisheries', Land Economics, vol. 72, no. 2, pp. 187-205.

Ferrol-Schulte, D, Wolff, M, Ferse, S & Glaser, M 2013, 'Sustainable Livelihoods Approach in tropical coastal and marine social–ecological systems: A review', Marine Policy, vol. 42, pp. 253-258.

Ferse, SCA, Costa, MM, Máñez, KS, Adhuri, DS & Glaser, M 2010, 'Allies, not aliens: increasing the role of local communities in marine protected area implementation', Environmental Conservation, vol. 37, no. 1, p. 12.

Finkbeiner, EM 2015, 'The role of diversification in dynamic small-scale fisheries: lessons from Baja California Sur, Mexico', Global Environmental Change, vol. 32, pp. 139-52.

Fischer, J, Peterson, GD, Gardner, TA, Gordon, LJ, Fazey, I, Elmqvist, T, Felton, A, Folke, C & Dovers, S 2009, 'Integrating resilience thinking and optimisation for conservation', Trends in Ecology and Evolution, vol. 24, no. 10, pp. 549-54.

Fisher, B & Christopher, T 2007, 'Poverty and biodiversity: measuring the overlap of human poverty and the biodiversity hotspots', Ecological Economics, vol. 62, no. 1, pp. 93-101.

Fisher, LA, Kim, Y-S, Latifah, S & Mukarom, M 2017, 'Managing forest conflicts: perspectives of Indonesia's forest management unit directors', Forest and Society, vol. 1, no. 1, pp. 8-26.

Fitzgerald, L 2007, 'Assessing the capacity to implement cross-scale co-management on Kaledupa, in the Wakatobi Marine National Park, Indonesia', Departments of Geography, vol. BA (Hons), p. 74.

Folke, C 2004, 'Traditional knowledge in social-ecological systems', Ecology and Society, vol. 9, no. 3, p. 7.

Folke, C, Carpenter, SR, Walker, B, Scheffer, M, Chapin, T & Rockström, J 2010, 'Resilience thinking: integrating resilience, adaptability and transformability', Ecology and Society, vol. 15, no. 4, p. 20.

Folke, C, Hahn, T, Olsson, P & Norberg, J 2005, 'Adaptive governance of social-ecological systems', Annual Review of Environment and Resources, vol. 30, no. 1, pp. 441-73.

Ford, A 2010, Modeling the environment, 2nd edn, Island Press, London.

Fortes, MD 1988, 'Mangrove and seagrass beds of East Asia: habitats under stress', Ambio, vol. 17, no. 3, pp. 207-13.

Fox, HE, Pet, JS, Dahuri, R & Caldwell, RL 2003, 'Recovery in rubble fields: long-term impacts of blast fishing', Mar Pollut Bull, vol. 46, no. 8, pp. 1024-31.

Fröcklin, S, Jiddawi, NS & de la Torre-Castro, M 2018, 'Small-scale innovations in coastal communities: shell-handicraft as a way to empower women and decrease poverty', Ecology and Society, vol. 23, no. 2, p. 34.

Fulton, EA, Smith, ADM, Smith, DC & van Putten, IE 2011, 'Human behaviour: the key source of uncertainty in fisheries management', Fish and Fisheries, vol. 12, no. 1, pp. 2-17.

Gardner, CJ, Rocliffe, S, Gough, C, Levrel, A, Singleton, RL, Vincke, X & Harris, A 2017, 'Value chain challenges in two community-managed fisheries in Western Madagascar: insights for the small-scale fisheries guidelines', in The Small-Scale Fisheries Guidelines, pp. 335-54, DOI 10.1007/978-3-319-55074-9_16.

Garland, J & Bradley, E 2015, 'Prediction in projection', Chaos, vol. 25, no. 12, p. 123108.

Garmestani, AS, Allen, CR & Benson, MH 2013, 'Can law foster social-ecological resilience?', Ecology and Society, vol. 18, no. 2, p. 6.

Gelcich, S, Edwards-Jones, G & Kaiser, MJ 2005, 'Importance of attitudinal differences among artisanal fishers toward co-management and conservation of marine resources', Conservation Biology, vol. 19, no. 3, pp. 865-75.

Gezelius, SS & Hauck, M 2011, 'Toward a theory of compliance in state-regulated livelihoods: a comparative study of compliance motivations in developed and developing world fisheries', Law & Society Review, vol. 45`, no. 2, pp. 435-70.

Glaeser, B & Glaser, M 2010, 'Global change and coastal threats: the Indonesian case. An attempt in multi-level social-ecological research', Research in Human Ecology, vol. 17, no. 2, pp. 135-47.

Glaser, M, Baitoningsih, W, Ferse, S, Neil, M & Deswandi, R 2010, 'Whose sustainability? Top-down participation and emergent rules in marine protected area management in Indonesia', Marine Policy, vol. 34, no. 6, pp. 1215-1225.

Glaser, M, Christie, P, Diele, K, Dsikowitzky, L, Ferse, S, Nordhaus, I, Schlüter, A, Schwerdtner Mañez, K & Wild, C 2012, 'Measuring and understanding sustainability-enhancing processes in tropical coastal and marine social–ecological systems', Current Opinion in Environmental Sustainability, vol. 4, no. 3, pp. 300-8.

Glaser, M & Glaeser, B 2014, 'Towards a framework for cross-scale and multi-level analysis of coastal and marine social-ecological systems dynamics', Regional Environmental Change, vol. 14, no. 6, pp. 2039-52.

Glaser, M, Krause, G, Ratter, BMW & Welp, M 2012, 'Towards global sustainability analysis in the anthropocene', in M Glaser, G Krause, BMW Ratter & M Welp (eds), Human-Nature Interactions in the Anthropocene: Potentials of Social-Ecological Systems Analysis. Routledge Studies in Environment, Culture, and Society, Taylor and Francis, New Yori, pp. 199-222.

Glaser, M, Radjawali, I & Ferse, S 2010, ''Nested' participation in hierarchical societies? Lessons for social-ecological research and management', International Journal of Society Systems Science, vol. 2, no. 4, pp. 390-414.

Graham, AK 1976, 'Parameter formulation and estimation in system dynamics models', in The 1976 International Conference on System Dynamics, Geilo, Norway, pp. 541-80.

Gratwicke, B & Speight, MR 2005, 'The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats', Journal of Fish Biology, vol. 66, pp. 650-667.

Gunderson, LH & Holling, CS 2002, Panarchy: understanding transformations in human and natural systems, Island Press, Washington DC.

Haeruman, H 1988, 'Conservation in Indonesia', Ambio, vol. 17, no. 3, pp. 218-22.

Halim, A 2002, 'Adoption of cyanide fishing practice in Indonesia', Ocean & Coastal Management, vol. 45, pp. 313-23.

Hall, C, Clayton, R, Anderson, R & Ouzounis, E 2011, Inter-X: Resilience of the internet interconnection ecosystem. Summary Report – April 2011, European Network and Information Security Agency.

Halliday, A & Glaser, M 2011, 'A management perspective on social ecological systems: a generic system model and its application to a case study from Peru', Human Ecology Review, vol. 18, no. 1, pp. 1-18.

Hamby, D 1994, 'A review of techniques for parameter sensitivity analysis of environmental models', Environ Monit Assess, vol. 32, no. 2, pp. 135-54.

Handoyo 2014, Industri Pengalengan Ikan Kekurangan Bahan Baku (=Fish Canning Industry Face Shortage), Kontan, viewed 15 March 2014, <http://industri.kontan.co.id/news/industri-pengalengan-ikan-kekurangan-bahan-baku>.

Hannon, B & Ruth, M 2014, 'Modeling dynamic biological systems', in Modeling dynamic biological systems, Springer, pp. 3-28.

Hauck, M 2008, 'Rethinking small-scale fisheries compliance', Marine Policy, vol. 32, no. 4, pp. 635-42.

Heithaus, MR, Frid, A, Wirsing, AJ & Worm, B 2008, 'Predicting ecological consequences of marine top predator declines', Trends in Ecology and Evolution, vol. 23, no. 4, pp. 202-10.

Hill, H 2008, 'The challenge of regional development in Indonesia', Australian Journal of International Affairs, vol. 52, no. 1, pp. 19-34.

Hirsch Hadorn, G, Bradley, D, Pohl, C, Rist, S & Wiesmann, U 2006, 'Implications of transdisciplinarity for sustainability research', Ecological Economics, vol. 60, no. 1, pp. 119-28.

Hirschman, C 1994, 'Population and society in twentieth-century Southeast Asia', J Southeast Asian Stud, vol. 25, no. 2, pp. 381-416.

Hoegh-Guldberg, O, Hoegh-Guldberg, H, Veron, JEN, Green, A, Gomez, ED, Lough, J, King, M, Ambariyanto, Hansen, L, Cinner, J, Dews, G, Russ, G, Schuttenberg, HZ, Peñaflor, EL, Eakin, CM, Christensen, TRL, Abbey, M, Areki, F, Kosaka, RA, Tewfik, A & Oliver, J 2009, The coral triangle andcClimate change: ecosystems, people and societies at risk., WWF Australia, Brisbane.

Hoegh-Guldberg, O, Mumby, PJ, Hooten, AJ, Steneck, RS, Greenfield, P, Gomez, E, Harvell, CD, Sale, PF, Edwards, AJ, Caldeira, K, Knowlton, N, Eakin, CM, Iglesias-Prieto, R, Muthiga, N, Bradbury, RH, Dubi, A & Hatziolos, ME 2007, 'Coral reefs under rapid climate change and ocean acidification', Science, vol. 318, no. 5857, pp. 1737-42.

Hoeksema, BW 2007, 'Delineation of the Indo-Malayan centre of maximum marine biodiversity: the coral triangle', in W Renema (ed.), Biogeography, time, and pace: distributions, barriers, and islands, Springer, Netherlands, vol. 29, pp. 117-78.

Holdschlag, A & Ratter, BMW 2013, 'Multiscale system dynamics of humans and nature in the Bahamas: perturbation, knowledge, panarchy and resilience', Sustainability Science, vol. 8, no. 3, pp. 407-21.

Holling, CS 2001, 'Understanding the complexity of economic, ecological, and social systems', Ecosystems, vol. 4, no. 5, pp. 390-405.

Holling, CS & Meffe, GK 1996, 'Command and control and the pathology of natural resource management', Conservation Biology, vol. 10, no. 2, pp. 328-37.

Hoshino, E, van Putten, EI, Girsang, W, Resosudarmo, BP & Yamazaki, S 2017, 'Fishers' perceived objectives of community-based coastal resource management in the Kei Islands, Indonesia', Frontiers in Marine Science, vol. 4.

Hovmand, PS 2014, 'Group model building and community-based system dynamics process', in Community Based System Dynamics, Springer New York, pp. 17-30, DOI 10.1007/978-1-4614-8763-0_2.

Huber-Sannwald, E, Palacios, MR, Moreno, JT, Braasch, M, Pena, RM, Verduzco, JG & Santos, KM 2012, 'Navigating challenges and opportunities of land degradation and sustainable livelihood development in dryland social-ecological systems: a case study from Mexico', Philosophical transactions of the Royal Society of London. Series B, Biological sciences, vol. 367, no. 1606, pp. 3158-77.

Huff, G & Angeles, L 2011, 'Globalization, industrialization and urbanization in Pre-World War II Southeast Asia', Explorations in Economic History, vol. 48, no. 1, pp. 20-36.

Hughes, TP, Bellwood, DR, Folke, C, Steneck, RS & Wilson, J 2005, 'New paradigms for supporting the resilience of marine ecosystems', Trends in Ecology and Evolution, vol. 20, no. 7, pp. 380-6.

Hughes, TP, Graham, NA, Jackson, JB, Mumby, PJ & Steneck, RS 2010, 'Rising to the challenge of sustaining coral reef resilience', Trends in Ecology and Evolution, vol. 25, no. 11, pp. 633-42.

Hughes, TP, Rodrigues, MJ, Bellwood, DR, Ceccarelli, D, Hoegh-Guldberg, O, McCook, L, Moltschaniwskyj, N, Pratchett, MS, Steneck, RS & Willis, B 2007, 'Phase shifts, herbivory, and the resilience of coral reefs to climate change', Current Biology, vol. 17, no. 4, pp. 360-5.

Ibelings, BW, Portielje, R, Lammens, EHRR, Noordhuis, R, van den Berg, MS, Joosse, W & Meijer, ML 2007, 'Resilience of alternative stable states during the recovery of shallow lakes from eutrophication: Lake Veluwe as a case study', Ecosystems, vol. 10, no. 1, pp. 4-16.

Ifejika Speranza, C, Wiesmann, U & Rist, S 2014, 'An indicator framework for assessing livelihood resilience in the context of social–ecological dynamics', Global Environmental Change, vol. 28, pp. 109-19.

Iman, RL & Helton, JC 1988, 'An investigation of uncertainty and sensitivity analysis techniques for computer models', Risk Analysis, vol. 8, no. 1, pp. 71-90.

IMF 2014, World economic outlook - April 2014, International Monetary Fund, Washington, DC, <http://www.imf.org/external/pubs/ft/weo/2014/01/pdf/text.pdf>.

IPCC 2014a, Climate change 2014: impacts, adaptation, and vulnerability. part a: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.

—— 2014b, Climate change 2014: impacts, adaptation, and vulnerability. part a: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change, Cambridge, United Kingdom and New York, NY, USA.

ISEES 2006, Module 6: Systems archetype. Archetype family tree, ISEE Systems, 25 May 2016, Training module, <http://www.iseesystems.com/Online_training/course/module6/6-03-0-0-tree.htm>.

Ito, T, Rachman, NF & Savitri, LA 2014, 'Power to make land dispossession acceptable: a policy discourse analysis of the Merauke integrated food and energy estate (MIFEE), Papua Indonesia', The Journal of Peasant Studies, vol. 41, no. 1, pp. 29-50.

Jackson, MC 2003, Systems thinking: creative holism for managers, John Wiley & Sons, West Sussex.

Jacquet, J & Pauly, D 2008, 'Funding priorities: big barriers to small-scale fisheries', Conserv Biol, vol. 22, no. 4, pp. 832-5.

Janssen, MA, Schoon, ML, Ke, W & Börner, K 2006, 'Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change', Global Environmental Change, vol. 16, no. 3, pp. 240-52.

Jasinski, JPP & Payette, S 2005, 'The creation of alternative stable states in the southern boral forest, Québec, Canada', Ecological Monographs, vol. 75, no. 4, p. 561-583.

Jentoft, S 1989, 'Fisheries co-management: delegating government responsibility to fishermen's organization', Marine Policy, vol. 13, no. 2, pp. 137-54

—— 2000, 'Legitimacy and disappointment in fisheries management', Marine Policy, vol. 24, no. 2, pp. 141–8.

Jentoft, S & Chuenpagdee, R 2009, 'Fisheries and coastal governance as a wicked problem', Marine Policy, vol. 33, no. 4, pp. 553-60.

Jentoft, S & Eide, A 2011, Poverty mosaics: realities and prospects in small-scale fisheries, Springer, Dordrecht.

Johnson, FA, Williams, BK & Nichols, JD 2013, 'Resilience thinking and a decision-analytic approach to conservation: strange bedfellows or essential partners?', Ecology and Society, vol. 18, no. 2, p. 17.

Jones, PJS, De Santo, EM, Qiu, W & Vestergaard, O 2013, 'Introduction: an empirical framework for deconstructing the realities of governing marine protected areas', Marine Policy, vol. 41, pp. 1-4.

Jørgensen, SE 2009, Ecosystem ecology, Elsevier, Amsterdam.

Joseph, V, Thornton, A, Pearson, S & Paull, D 2013, 'Occupational transitions in three coastal villages in Central Java, Indonesia, in the context of sea level rise: a case study', Natural Hazards, vol. 69, no. 1, pp. 675-94.

Jupiter, SD, Cohen, PJ, Weeks, R, Tawake, A & Govan, H 2014, 'Locally-managed marine areas: multiple objectives and diverse strategies', Pacific Conservation Biology, vol. 20, no. 2, p. 15.

Karr, KA, Fujita, R, Halpern, BS, Kappel, CV, Crowder, L, Selkoe, KA, Alcolado, PM & Rader, D 2015, 'Thresholds in Caribbean coral reefs: implications for ecosystem-based fishery management', Journal of Applied Ecology, vol. 52, no. 2, pp. 402-12.

KBBI 2014, 'Cahari', viewed 10 November 2014, <http://kbbi.web.id/cahari>.

Khan, N, McLucas, A & Linard, K 2004, 'Development of a reference mode for characterisation of salinity problem in the Murray Darling Basin.', in M Kennedy, GW Winch, RS Langer, JI Rowe & JM Yanni (eds), 22nd International Conference of the System Dynamics Society, Oxford, England, p. 29.

Kim, DH 1998, Systems archetype basics: from stories to structures, Pegasus Communications, Inc., Westford, MA.

Kinzig, AP, Ryan, P, Etienne, M, Allison, H, Elmqvist, T & Walker, BH 2006, 'Resilience and regime shifts: assessing cascading effects', Ecology and Society, vol. 11, no. 1, p. 20.

Kittinger, JN, Finkbeiner, EM, Ban, NC, Broad, K, Carr, MH, Cinner, JE, Gelcich, S, Cornwell, ML, Koehn, JZ, Basurto, X, Fujita, R, Caldwell, MR & Crowder, LB 2013, 'Emerging frontiers in social-ecological systems research for sustainability of small-scale fisheries', Current Opinion in Environmental Sustainability, vol. 5, no. 3-4, pp. 352-7.

Klein, E, Glaser, S, Jordaan, A, Kaufman, L & Rosenberg, A 2016, 'A complex past: historical and contemporary fisheries demonstrate nonlinear dynamics and a loss of determinism', Marine Ecology Progress Series, vol. 557, pp. 237-46.

Knowlton, N & Jackson, JB 2008, 'Shifting baselines, local impacts, and global change on coral reefs', PLoS Biol, vol. 6, no. 2, p. e54.

Koch, EW, Barbier, EB, Silliman, BR, Reed, DJ, Perillo, GME, Hacker, SD, Granek, EF, Primavera, JH, Muthiga, N, Polasky, S, Halpern, BS, Kennedy, CJ, Kappel, CV & Wolanski, E 2009, 'Non-linearity in ecosystem services: temporal and spatial variability in coastal protection', Frontiers in Ecology and the Environment, vol. 7, no. 1, pp. 29-37.

Koeshendrajana, S & Hartono, TT 2006, 'Indonesian live reef fish industry: status, problems and possible future direction', in B Johnston & B Yeeting (eds), Economics and marketing of the live reef fish trade in Asia–Pacific, ACIAR, pp. 74-163.

Kollmuss, A & Agyeman, J 2002, 'Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior?', Environmental Education Research, vol. 8, no. 3, pp. 239-60.

Kontan 2013, Ekspor Ikan Mentah Akan Dikurangi (=Raw Fish Export will be Reduced), Tribunnews.com, viewed 15 March 2014, <http://www.tribunnews.com/bisnis/2013/12/04/ekspor-ikan-mentah-akan-dikurangi>.

Korhonen-Kurki, K, Sehring, J, Brockhaus, M & Di Gregorio, M 2013, 'Enabling factors for establishing REDD+ in a context of weak governance', Climate Policy, vol. 14, no. 2, pp. 167-86.

Krueger, RA & Casey, MA 2009, Focus groups: a practical guide for applied research, SAGE Publications.

Lambin, EF & Meyfroidt, P 2010, 'Land use transitions: Socio-ecological feedback versus socio-economic change', Land Use Policy, vol. 27, no. 2, pp. 108-18.

Lang, K 2007, Poverty and discrimination, Princeton University Press, NJ.

Larsen, RK, Swartling, ÅG, Powell, N, May, B, Plummer, R, Simonsson, L & Osbeck, M 2012, 'A framework for facilitating dialogue between policy planners and local climate change adaptation professionals: cases from Sweden, Canada and Indonesia', Environmental Science & Policy, vol. 23, pp. 12-23.

Leavy, P 2014, The Oxford handbook of qualitative research, Oxford Library of Psychology, New York.

Leopold, A 1981, A Sand County almanac: and sketches here and there, Oxford University Press, New York.

Leslie, HM, Basurto, X, Nenadovic, M, Sievanen, L, Cavanaugh, KC, Cota-Nieto, JJ, Erisman, BE, Finkbeiner, E, Hinojosa-Arango, G, Moreno-Baez, M, Nagavarapu, S, Reddy, SM, Sanchez-Rodriguez, A, Siegel, K, Ulibarria-Valenzuela, JJ, Weaver, AH & Aburto-Oropeza, O 2015, 'Operationalizing the social-ecological systems framework to assess sustainability', Proc Natl Acad Sci U S A, vol. 112, no. 19, pp. 5979-84.

Levin, S, Xepapadeas, T, Crépin, A-S, Norberg, J, de Zeeuw, A, Folke, C, Hughes, T, Arrow, K, Barrett, S, Daily, G, Ehrlich, P, Kautsky, N, Mäler, K-G, Polasky, S, Troell, M, Vincent, JR & Walker, B 2012, 'Social-ecological systems as complex adaptive systems: modeling and policy implications', Environment and Development Economics, vol. 18, no. 02, pp. 111-32.

Lindenmayer, DB, Hobbs, RJ, Likens, GE, Krebs, CJ & Banks, SC 2011, 'Newly discovered landscape traps produce regime shifts in wet forests', Proc Natl Acad Sci U S A, vol. 108, no. 38, pp. 15887-91.

Maani, KE & Cavana, RY 2007, Systems thinking, systems dynamics: managing change and complexity, Second edn, Pearson Education New Zealand, Auckland, N.Z.

Mahon, R, McConney, P & Roy, RN 2008, 'Governing fisheries as complex adaptive systems', Marine Policy, vol. 32, no. 1, pp. 104-12.

Mahoney, J 2000, 'Path dependence in historical sociology', Theory and Society, vol. 294, no. 4, p. 42.

—— 2001, 'Path-dependent explanations of regime change: Central America in comparative perspective', Studies in Comparative International Development, vol. 36, no. 1, p. 31.

Mai, T & Smith, C 2015, 'Addressing the threats to tourism sustainability using systems thinking: a case study of Cat Ba Island, Vietnam', Journal of Sustainable Tourism, vol. 23, no. 10, pp. 1504-28.

Mangi, SC, Roberts, CM & Rodwell, LD 2007, 'Reef fisheries management in Kenya: preliminary approach using the driver–pressure–state–impacts–response (DPSIR) scheme of indicators', Ocean & Coastal Management, vol. 50, no. 5-6, pp. 463-80.

Marnane, MJ, Ardiwijaya, RL, WIbowo, JT, Pardede, ST, Mukminin, A & Herdiana, Y 2004, Studi Perikanan Muro-ami Kepulauan Karimunjawa 2003, Wildlife Conservation Society - Marine Program Indonesia, Bogor, Indonesia.

Marschke, M & Berkes, F 2006, 'Exploring strategies that build livelihood resilience: a case from Cambodia', Ecology and Society, vol. 11, no. 1, p. 42.

Marshall, N, Fenton, D, Marshall, P & Sutton, S 2007, 'How resource dependency can influence social resilience within a primary resource industry', Rural Sociology, vol. 72, no. 3, pp. 359-90.

Marshall, NA, Tobin, RC, Marshall, PA, Gooch, M & Hobday, AJ 2013, 'Social vulnerability of marine resource users to extreme weather events', Ecosystems, vol. 16, no. 5, pp. 797-809.

Mathers, CD & Loncar, D 2006, 'Projections of global mortality and burden of disease from 2002 to 2030', PLoS Med, vol. 3, no. 11, p. e442.

Matott, LS, Babendreier, JE & Purucker, ST 2009, 'Evaluating uncertainty in integrated environmental models: a review of concepts and tools', Water Resources Research, vol. 45, no. 6, pp. n/a-n/a.

Maynard, JA, Anthony, KRN, Afatta, S, Anggraini, LF, Haryanti, D & Ambariyanto 2008, 'Rock anchoring in Karimun Jawa, Indonesia: ecological impacts and management implications', Pacific Conservation Biology, vol. 14, no. 4, p. 2.

McClanahan, T 1995, 'A coral reef ecosystem-fisheries model: impacts of fishing intensity and catch selection on reef structure and processes', Ecological Modelling, vol. 80, no. 1, p. 19.

McClanahan, T, Allison, EH & Cinner, JE 2015, 'Managing fisheries for human and food security', Fish and Fisheries, vol. 16, no. 1, pp. 78-103.

McClanahan, T & Mangi, S 2000, 'Spillover of exploitable fishes from a marine park and its effect on the adjacent fishery', Ecological Applications, vol. 10, no. 6, p. 15.

McClanahan, TR, Graham, NA, MacNeil, MA, Muthiga, NA, Cinner, JE, Bruggemann, JH & Wilson, SK 2011, 'Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries', Proc Natl Acad Sci U S A, vol. 108, no. 41, pp. 17230-3.

McClanahan, TR, Marnane, MJ, Cinner, JE & Kiene, WE 2006, 'A comparison of marine protected areas and alternative approaches to coral-reef management', Current Biology, vol. 16, no. 14, pp. 1408-13.

McLeod, E, Moffitt, R, Timmermann, A, Salm, R, Menviel, L, Palmer, M, Selig, E, Casey, K & Bruno, J 2010, 'Warming seas in the coral triangle: coral reef vulnerability and Mmnagement implications', Coastal Management, vol. 38, no. 5, pp. 518-39.

McWhinnie, SF 2009, 'The tragedy of the commons in international fisheries: an empirical examination', Journal of Environmental Economics and Management, vol. 57, no. 3, pp. 321-33.

Meadows, D 1999, Leverage points: place to intervene in a system., The Sustainability Institute, Hartland.

Meadows, DH 2009, Thinking in systems. A primer, Earthscan, London, New York.

Merino, G, Barange, M, Blanchard, JL, Harle, J, Holmes, R, Allen, I, Allison, EH, Badjeck, MC, Dulvy, NK, Holt, J, Jennings, S, Mullon, C & Rodwell, LD 2012, 'Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate?', Global Environmental Change, vol. 22, no. 4, pp. 795-806.

Merriam-Webster 2014, 'Livelihood', viewed 10 November 2014, <http://www.merriam-webster.com/dictionary/livelihood>.

Millennium Ecosystem Assessment 2005a, Ecosystems and human well-being: current state and trends, Island Press, Washington DC, <http://www.unep.org/maweb/en/Global.aspx>.

—— 2005b, Ecosystems and human well-being: general synthesis, Island Press, Washington DC, <http://www.unep.org/maweb/en/Global.aspx>.

—— 2005c, Ecosystems and human well-being: scenarios, Island Press, Washington DC, <http://www.unep.org/maweb/en/Global.aspx>.

Miller, BW, Caplow, SC & Leslie, PW 2012, 'Feedbacks between conservation and social-ecological systems', Conservation Biology, vol. 26, no. 2, pp. 218-27.

Miller, F, Osbahr, H, Boyd, E, Thomalla, F, Bharwani, S, Ziervogel, G, Walker, B, Birkmann, Jr, Leeuw, Svd, Rockström, J, Hinkel, J, Downing, T, Folke, C & Nelson, D 2010, 'Resilience and vulnerability: complementary or conflicting concepts?', Ecology and Society, vol. 15, no. 3, p. 1.

Mills, DJ, Adhuri, DS, Phillips, MJ, Ravikumar, B & Padiyar, AP 2011, 'Shocks, recovery trajectories and resilience among aquaculture-dependent households in post-tsunami Aceh, Indonesia', Local Environment, vol. 16, no. 5, pp. 425-44.

Miñarro, S, Navarrete Forero, G, Reuter, H & van Putten, IE 2016, 'The role of patron-client relations on the fishing behaviour of artisanal fishermen in the Spermonde Archipelago (Indonesia)', Marine Policy, vol. 69, pp. 73-83.

MMAF 2013, Kelautan dan Perikanan Dalam Angka (=Marine and Fisheries in Figures) 2013, Ministry of Marine Affairs and Fisheries of Indonesia.

Moberg, F & Folke, C 1999, 'Ecological goods and services of coral reef ecosystems', Ecological Economics, no. 29, p. 19.

Mollona, E 2011, 'How do system dynamic models (SD) capture path dependent and complex evolutionary behaviour in social science analysis?', in The 29th International Conference of the System Dynamics Society, Washington, DC, p. 22.

Moore, M-L & Westley, F 2011, 'Surmountable chasms: networks and social Innovation for resilient systems', Ecology and Society, vol. 16, no. 1, p. 5.

Mora, C, Wei, CL, Rollo, A, Amaro, T, Baco, AR, Billett, D, Bopp, L, Chen, Q, Collier, M, Danovaro, R, Gooday, AJ, Grupe, BM, Halloran, PR, Ingels, J, Jones, DO, Levin, LA, Nakano, H, Norling, K, Ramirez-Llodra, E, Rex, M, Ruhl, HA, Smith, CR, Sweetman, AK, Thurber, AR, Tjiputra, JF, Usseglio, P, Watling, L, Wu, T & Yasuhara, M 2013, 'Biotic and human vulnerability to projected changes in ocean biogeochemistry over the 21st century', PLoS Biol, vol. 11, no. 10, p. e1001682.

Morgan, GR & Staples, DJ 2006, The history of industrial marine fisheries in Southeast Asia, RAP Publication 2006/12, Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok.

Mous, PJ, Pet-Soede, L, Erdmann, M & Cesar, H 2000, 'Cyanide fishing on Indonesian coral reefs for the live food fish market—What is the problem?', SPC Live Reef Fish Information Bulletin.

Munday, PL, Dixson, DL, Donelson, JM, Jones, GP, Pratchett, MS, Devitsina, GV & Doving, KB 2009, 'Ocean acidification impairs olfactory discrimination and homing ability of a marine fish', Proc Natl Acad Sci U S A, vol. 106, no. 6, pp. 1848-52.

Myers-Smith, IH, Trefry, SA & Swarbrick, VJ 2012, 'Resilience: easy to use but hard to define', Ideas in Ecology and Evolution, vol. 5, no. 1.

Nagelkerken, I, Blaber, SJM, Bouillon, S, Green, P, Haywood, M, Kirton, LG, Meynecke, JO, Pawlik, J, Penrose, HM, Sasekumar, A & Somerfield, PJ 2008, 'The habitat function of mangroves for terrestrial and marine fauna: a review', Aquatic Botany, vol. 89, no. 2, pp. 155-85.

Nathan, AJ 2003, 'Authoritarian resilience', Journal of Democracy, vol. 14, no. 1, p. 12.

Nayak, PK, Oliveira, LE & Berkes, F 2014, 'Resource degradation, marginalization, and poverty in small-scale fisheries: threats to social-ecological resilience in India and Brazil', Ecology and Society, vol. 19, no. 2, p. 73.

Nelson, DR, Adger, WN & Brown, K 2007, 'Adaptation to environmental change: contributions of a resilience framework', Annual Review of Environment and Resources, vol. 32, no. 1, pp. 395-419.

Neumann, B, Vafeidis, AT, Zimmermann, J & Nicholls, RJ 2015, 'Future coastal population growth and exposure to sea-level rise and coastal flooding--a global assessment', PLoS One, vol. 10, no. 3, p. e0118571.

Nguyen, NC & Bosch, OJH 2013, 'A systems thinking approach to identify leverage points for sustainability: a case study in the Cat Ba Biosphere Reserve, Vietnam', Systems Research and Behavioral Science, vol. 30, no. 2, pp. 104-15.

Nguyen, NC, Graham, D, Ross, H, Maani, K & Bosch, O 2012, 'Educating systems thinking for sustainability: experience with a developing country', Systems Research and Behavioral Science, vol. 29, no. 1, pp. 14-29.

Niesten, E, Gjertsen, H & Fong, PS 2012, 'Incentives for marine conservation: options for small island developing states', Environment and Development Economics, vol. 18, no. 4, pp. 440-58.

Nizar, M 2015, 'Analisis Keberlanjutan Usaha Budidaya Rumput Laut Pada Penerima Paket Bantuan Langsung Masyarakat Di Kabupaten Muna', Masters thesis, Universitas Terbuka.

Nkhata, AB, Breen, CM & Freimund, WA 2008, 'Resilient Social Relationships and Collaboration in the Management of Social–Ecological Systems', Ecology and Society, vol. 13, no. 1, p. 2.

Norström, A, Nyström, M, Lokrantz, J & Folke, C 2009, 'Alternative states on coral reefs: beyond coral-macroalgal phase shifts', Marine Ecology Progress Series, vol. 376, pp. 295-308.

Nurdin, N & Grydehøj, A 2014, 'Informal governance through patron–client relationships and destructive fishing in Spermonde Archipelago, Indonesia', Journal of Marine and Island Cultures, vol. 3, no. 2, pp. 54-9.

O'Shea, B & Thompson, S 2006, 'The innovative application of vessel monitoring systems for the effective fisheries monitoring control and surveillance', ICES Document CM, vol. 11, pp. 1-25.

Österblom, H, Merrie, A, Metian, M, Boonstra, WJ, Blenckner, T, Watson, JR, Rykaczewski, RR, Ota, Y, Sarmiento, JL, Christensen, V, Schlüter, M, Birnbaum, S, Gustafsson, BG, Humborg, C, Mörth, C-M, Müller-Karulis, Br, Tomczak, MT, Troell, M & Folke, C 2013, 'Modeling social–ecological scenarios in marine systems', BioScience, vol. 63, no. 9, pp. 735-44.

Ostrom, E 2009, 'A general framework for analyzing sustainability of social-ecological systems', Science, vol. 325, no. 5939, pp. 419-22.

Ostrom, E & Cox, M 2010, 'Moving beyond panaceas: a multi-tiered diagnostic approach for social-ecological analysis', Environmental Conservation, vol. 37, no. 04, pp. 451-63.

Palomares, MLD & Heymans, JJ 2006, 'Historical Ecology of the Raja Ampat Archipelago, Papua Province, Indonesia', Fisheries Centre Research Reports, vol. 14, no. 7, p. 64.

Parsons, T 2005, The social system, Routledge Sociology Classics, Taylor & Francis, London.

Partelow, S 2015, 'Key steps for operationalizing social–ecological system framework research in small-scale fisheries: A heuristic conceptual approach', Marine Policy, vol. 51, pp. 507-11.

Pauly, D 1987, 'Theory and practice of overfishing: a Southeast Asian perspective', paper presented to the Symposium on the Exploitation and Management of Marine Fishery Resources in Southeast Asia, Darwin, Australia, 16 - 26 February 1987.

Pauly, D, Christensen, VV, Dalsgaard, J, Froese, R & Torres, F, Jr. 1998, 'Fishing down marine food webs', Science, vol. 279, no. 5352, pp. 860-3.

Peñaflor, E, Skirving, W, Strong, A, Heron, S & David, L 2009, 'Sea-surface temperature and thermal stress in the Coral Triangle over the past two decades', Coral Reefs, vol. 28, no. 4, pp. 841-50.

Pershing, AJ, Alexander, MA, Hernandez, CM, Kerr, LA, Le Bris, A, Mills, KE, Nye, JA, Record, NR, Scannell, HA, Scott, JD, Sherwood, GD & Thomas, AC 2015, 'Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery', Science, vol. 350, no. 6262, pp. 809-12.

Pet, JS, Mous, PJ, Muljadi, AH, Sadovy, YJ & Squire, L 2005, 'Aggregations of plectropomus areolatus and epinephelus fuscoguttatus (groupers, Serranidae) in the Komodo National Park, Indonesia: monitoring and implications for management', Environmental Biology of Fishes, vol. 74, no. 2, pp. 209-18.

Pet-Soede, C, Densen, WLTV, Hiddink, JG, Kuyl, S & Machiels, MAM 2001, 'Can fishermen allocate their fishing effort in space and time on the basis of their catch rates? An example from Spermonde Archipelago, SW Sulawesi, Indonesia', Fisheries Management and Ecology, vol. 8, pp. 15-36.

Pet-Soede, L & Erdmann, M 1998a, 'An overview and comparison of destructive fishing practices in Indonesia', SPC Live Reef Fish Information Bulletin, vol. 4, no. 1, pp. 28-36.

—— 1998b, 'Blast fishing in southwest Sulawesi, Indonesia', Naga, The ICLARM Quarterly, vol. 21, no. 2, p. 6.

Peterson, GD, Carpenter, SR & Brock, WA 2003, 'Uncertainty and the management of multistate ecosystems: an apparently rational route to collapse', Ecology, vol. 84, no. 6, pp. 1403 - 1411.

Pidwirny, M 2006, 'Equilibrium concepts and feedbacks', fundamentals of physical geography, 2nd edition, viewed 30 May 2016, <http://www.physicalgeography.net/fundamentals/4f.html>.

Pinnegar, JK, Polunin, N & Francour, P 2002, 'Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management', Environmental Conservation, vol. 27, no. 2, p. 22.

Platt, J 1973, 'Social traps', American Psychologist, vol. 28, no. 8, pp. 641-51.

Plummer, R 2009, 'The adaptive co-management process: an initial synthesis of representative models and influential variables', Ecology and Society, vol. 14, no. 2, p. 24.

Polasky, S, Carpenter, SR, Folke, C & Keeler, B 2011, 'Decision-making under great uncertainty: environmental management in an era of global change', Trends in Ecology and Evolution, vol. 26, no. 8, pp. 398-404.

Pollnac, R, Christie, P, Cinner, JE, Dalton, T, Daw, TM, Forrester, GE, Graham, NA & McClanahan, TR 2010, 'Marine reserves as linked social-ecological systems', Proc Natl Acad Sci U S A, vol. 107, no. 43, pp. 18262-5.

Pomeroy, R, Katon, B & Harkes, I 2001, 'Conditions affecting the success of fisheries co-management: lessons from Asia', Marine Policy, vol. 25, no. 3, pp. 197-208.

Pomeroy, R, Parks, J & Balboa, C 2006, 'Farming the reef: is aquaculture a solution for reducing fishing pressure on coral reefs?', Marine Policy, vol. 30, no. 2, pp. 111-30.

Pomeroy, R, Parks, J, Mrakovcich, KL & LaMonica, C 2016, 'Drivers and impacts of fisheries scarcity, competition, and conflict on maritime security', Marine Policy, vol. 67, pp. 94-104.

Pomeroy, RS & Andrew, NL 2011, Small-scale fisheries management: frameworks and approaches for the developing world, CABI.

Poteete, AR, Janssen, MA & Ostrom, E 2010, Working together: collective action, the commons, and multiple methods in practice, Princeton University Press, New Jersey.

Powell, N & Osbeck, M 2010, 'Approaches for understanding and embedding stakeholder realities in mangrove rehabilitation processes in Southeast Asia: lessons learnt from Mahakam Delta, East Kalimantan', Sustainable Development, vol. 18, no. 5, pp. 260-70.

Pratchett, MS, Munday, PL, Wilson, SK, Graham, NAJ, Cinner, JE, Bellwood, DR, Jones, GP, Polunin, NVC & McClanahan, TT 2008, 'Effects of climate-induced coral bleaching on coral-reef fishes - ecological and economic consequences', Oceanography and Marine Biology, vol. 46, pp. 251-9.

Purdy, DH, Kinch, J & Hadley, D 2015, Customary marine tenure and social-ecological dynamics in the Tigak Islands of Papua New Guinea, University of New England, Nago Island Mariculture and Research Facility., <https://www.researchgate.net/publication/275964347_Customary_marine_tenure_and_social-ecological_dynamics_in_the_Tigak_Islands_of_Papua_New_Guinea>.

Purwanto 1999, 'Status and role of aquaculture in rural development in Indonesia', in M Halwart, D Kumar & MG Bondad-Reantaso (eds), FAO/NACA Consultation on Aquaculture for Sustainable Rural Development, Chiang Rai, Thailand.

RA 2007, Assessing resilience in social-ecological systems. A workbook for scientists, Version 1.1. Draft for testing and evaluation edn, Resilience Alliance, <http://www.resalliance.org/index.php/resilience_assessment>.

Radel, C, Schmook, B & Chowdhury, RR 2010, 'Agricultural livelihood transition in the southern Yucatán region: diverging paths and their accompanying land changes', Regional Environmental Change, vol. 10, no. 3, pp. 205-18.

Radjawali, I 2012, 'Examining local conservation and development: live reef food fishing in Spermonde Archipelago, Indonesia', Revista de Gestão Costeira Integrada, vol. 12, no. 4, pp. 545-57.

Rahmstorf, S, Foster, G & Cazenave, A 2012, 'Comparing climate projections to observations up to 2011', Environmental Research Letters, vol. 7, no. 4, p. 44035.

Rammel, C, Stagl, S & Wilfing, H 2007, 'Managing complex adaptive systems--a co-evolutionary perspective on natural resource management', Ecological Economics, vol. 63, no. 1, pp. 9-21.

Rausa-Gomez, L 1967, 'Sri Yijava and Madjapahit', Philippine Studies, vol. 15, no. 1, pp. 63-107.

Raymond, CM, Fazey, I, Reed, MS, Stringer, LC, Robinson, GM & Evely, AC 2010, 'Integrating local and scientific knowledge for environmental management', J Environ Manage, vol. 91, no. 8, pp. 1766-77.

Reardon, T & Vosti, SA 1995, 'Links between rural poverty and the environment in developing countries: asset categories and investment poverty', World Development, vol. 23, no. 9, pp. 1495-506.

Reed, MS, Fraser, EDG & Dougill, AJ 2006, 'An adaptive learning process for developing and applying sustainability indicators with local communities', Ecological Economics, vol. 59, no. 4, pp. 406-18.

Resilience Alliance 2002, Resilience, resilience alliance, viewed 12 May 2015, <http://www.resalliance.org/index.php/resilience>.

—— 2003, Thresholds and regime shifts in ecological and social-ecological systems - a resilience alliance / Santa Fe Institute database, Resilience Alliance, viewed 12 June 2015, <http://www.resalliance.org/index.php/thresholds_database>.

Reynolds, M & Holwell, S 2010, Systems approaches to managing change: a practical guide, Springer, London.

Ripple, WJ & Beschta, RL 2006, 'Linking a cougar decline, trophic cascade, and catastrophic regime shift in Zion National Park', Biological Conservation, vol. 133, no. 4, pp. 397-408.

Robards, MD & Greenberg, JA 2007, 'Global constraints on rural fishing communities: whose resilience is it anyway?', Fish and Fisheries, vol. 8, no. 1, pp. 14-30.

Rogers, A, Blanchard, JL & Mumby, PJ 2014, 'Vulnerability of coral reef fisheries to a loss of structural complexity', Current Biology, vol. 24, no. 9, pp. 1000-5.

Rogers, DJ 2013, 'Managing ecological systems with unknown threshold locations', Ph.D. thesis, University of Sydney, <http://hdl.handle.net/2123/9981>.

Rogers, KH, Luton, R, Biggs, H, Biggs, R, Blignaut, S, Choles, AG, Palmer, CG & Tangwe, P 2013, 'Fostering complexity thinking in action research for change in social-ecological systems', Ecology and Society, vol. 18, no. 2, p.31.

Rudi, E, Iskandar, T, Fadli, N & Hidayati, H 2012, 'Impact of mass coral bleaching on reef fish community and fishermen catches at Sabang, Aceh Province, Indonesia.', Aquaculture, Aquarium, Conservation & Legislation - International Journal of the Bioflux Society, vol. 5, no. 5, pp. 309-20.

Ruitenbeek, J & Cartier, C 2001, The invisible wand: adaptive co-management as an emergent strategy in complex bio-economic systems, Centre for International Forestry Research (CIFOR), Jakarta.

Saeed, K 1998, 'Defining a problem or constrcting a reference mode', in The 16th International Conference of The System Dynamics Society, July 20 - 23, 1998, Québec.

Salafsky, N & Wollenberg, E 2000, 'Linking livelihoods and conservation: a conceptual framework and scale for assessing the integration of human needs and biodiversity', World Development, vol. 28, no. 8, pp. 1421-38.

Salmi, P 2015, 'Constraints and opportunities for small-scale fishing livelihoods in a post-productivist coastal setting', Sociologia Ruralis, vol. 55, no. 3, pp. 258-74.

Santillo, D 2007, 'Reclaiming the definition of sustainability (7 pp)', Environmental Science and Pollution Research - International, vol. 14, no. 1, pp. 60-6.

Satria, A & Matsida, Y 2016, 'Decentralization policy: an opportunity for strengthening fisheries management system?', The Journal of Environment & Development, vol. 13, no. 2, pp. 179-96.

Satria, A & Matsuda, Y 2004, 'Decentralization of fisheries management in Indonesia', Marine Policy, vol. 28, no. 5, p. 437.

Satria, A, Matsuda, Y & Sano, M 2006, 'Questioning community based coral reef management systems: case study of awig-awig in Gili Indah, Indonesia', Environment, Development and Sustainability, vol. 8, no. 1, pp. 99-118.

Scarlett, L 2013, 'Collaborative adaptive management: challenges and opportunities', Ecology and Society, vol. 18, no. 3, p.26.

Scheffer, M, Carpenter, S, Foley, JA, Folke, C & Walker, B 2001, 'Catastrophic shifts in ecosystems', Nature, vol. 413, no. 6856, pp. 591-6.

Scheffer, M & Carpenter, SR 2003, 'Catastrophic regime shifts in ecosystems: linking theory to observation', Trends Ecol Evol, vol. 18, no. 12, pp. 648-56.

Schreiber, E, Bearlin, A, Nicol, S & Todd, C 2004, 'Adaptive management: a synthesis of current understanding and effective application', Ecological Management & Restoration, vol. 5, no. 3, pp. 177-82.

Scoones, I 1998, Sustainable Rural Livelihoods: A framework for analysis., Institute of Development Studies, Brighton.

SEAFDEC 2003, Regional Guidelines for Responsible Fisheries in Southeast Asia: Fisheries Management, MFRDMD/SP3, Southeast Asian Fisheries Development Center/Marine Fishery Resources Development and Management Department (SEAFDEC/MFRDMD), Terengganu, Malaysia.

Senge, PM 2006, The fifth discipline: the art and practice of the learning organization, second edn, Random House Business, Sydney.

Sheriff, N, Little, DC & Tantikamton, K 2008, 'Aquaculture and the poor—Is the culture of high-value fish a viable livelihood option for the poor?', Marine Policy, vol. 32, no. 6, pp. 1094-102.

Sievanen, L, Crawford, B, Pollnac, R & Lowe, C 2005, 'Weeding through assumptions of livelihood approaches in ICM: seaweed farming in the Philippines and Indonesia', Ocean and Coastal Management, vol. 48, no. 3-6, pp. 297-313.

Simon, HA 1991, 'Bounded rationality and organizational learning', Organizational Science, vol. 2, no. 1, p. 11.

Slater, MJ, Napigkit, FA & Stead, SM 2013, 'Resource perception, livelihood choices and fishery exit in a Coastal Resource Management area', Ocean & Coastal Management, vol. 71, pp. 326-33.

Sloan, NA & Ugandhy, AS 1994, 'An overview of Indonesian coastal environmental management', Coastal Management, vol. 22, no. 3, p. 20.

Smit, B & Wandel, J 2006, 'Adaptation, adaptive capacity and vulnerability', Global Environmental Change, vol. 16, no. 3, pp. 282-92.

Smith, A & Stirling, A 2008, Social-ecological resilience and socio-technical transitions: critical issues for sustainability governance, STEPS Centre, Brighton, Working paper.

Smith, L, Khoa, S & Lorenzen, K 2005, 'Livelihood functions of inland fisheries: policy implications in developing countries', Water Policy, vol. 7, no. 4, pp. 359-83.

Sodhi, NS, Koh, LP, Brook, BW & Ng, PK 2004, 'Southeast Asian biodiversity: an impending disaster', Trends in Ecology and Evolution, vol. 19, no. 12, pp. 654-60.

Sodik, D 2009, 'Analysis of IUU fishing in Indonesia and the Indonesian legal framework reform for monitoring, control and surveillance of fishing vessels', The International Journal of Marine and Coastal Law, vol. 24, no. 1, pp. 67-100.

Song, AM, Chuenpagdee, R & Jentoft, S 2013, 'Values, images, and principles: what they represent and how they may improve fisheries governance', Marine Policy, vol. 40, pp. 167-75.

Spalding, M, Kainuma, M & Collins, L 2010, World atlas of mangrove, Earthscan, London.

SRC 2012, 'Interaction between social and ecological feedbacks can lock systems into unsustainable pathways, creating social-ecological traps', Research Insights, p. 4, <http://www.stockholmresilience.org/21/news--events/research-insights/insights/2-28-2012-insight-5-social-ecological-traps.html>.

St John, FAV, Edwards-Jones, G & Jones, JPG 2010, 'Conservation and human behaviour: lessons from social psychology', Wildlife Research, vol. 37, no. 8, pp. 658-67.

Stanford, RJ, Wiryawan, B, Bengen, DG, Febriamansyah, R & Haluan, J 2014, 'Enabling and constraining factors in the livelihoods of poor fishers in West Sumatra, Indonesia', Journal of International Development, vol. 26, no. 5, pp. 731-43.

Staver, AC, Archibald, S & Levin, S 2011, 'Tree cover in sub-Saharan Africa: rainfall and fire constrain forest and savanna as alternative stable states', Ecology, vol. 92, no. 5, p. 10.

Steneck, RS, Hughes, TP, Cinner, JE, Adger, WN, Arnold, SN, Berkes, F, Boudreau, SA, Brown, K, Folke, C, Gunderson, L, Olsson, P, Scheffer, M, Stephenson, E, Walker, B, Wilson, J & Worm, B 2011, 'Creation of a gilded trap by the high economic value of the Maine lobster fishery', Conservation Biology, vol. 25, no. 5, pp. 904-12.

Sterman, JD 2000, Business dynamics: systems thinking and modeling for a complex world, Irwin McGraw-Hill, Boston.

Stern, PC 2005, 'Deliberative methods for understanding environmental systems', BioScience, vol. 55, no. 11, p. 7.

Stobutzki, IC, Silvestre, GT & Garces, LR 2006, 'Key issues in coastal fisheries in South and Southeast Asia, outcomes of a regional initiative', Fisheries Research, vol. 78, no. 2-3, pp. 109-18.

Stringer, LC, Dougill, AJ, Fraser, E, Hubacek, K, Prell, C & Reed, MS 2006, 'Unpacking “participation” in the adaptive management of social– ecological systems: a critical review', Ecology and Society, vol. 11, no. 2, p. 39.

Suhari, SHM 2014, 'Gorontalo fishermen go out to sea despite bad weather', The Jakarta Post, October 23 2014, viewed 22 August 2015, <http://www.thejakartapost.com/news/2014/10/23/gorontalo-fishermen-go-out-sea-despite-bad-weather.html>.

Sumaila, UR, Cheung, WWL, Lam, VWY, Pauly, D & Herrick, S 2011, 'Climate change impacts on the biophysics and economics of world fisheries', Nature Climate Change, vol. 1, no. 9, pp. 449-56.

Suwarno, A, Nawir, AA, Julmansyah & Kurniawan 2009, 'Participatory modelling to improve partnership schemes for future community-based forest management in Sumbawa District, Indonesia', Environmental Modelling & Software, vol. 24, no. 12, pp. 1402-10.

Sydow, Jr, Schreyögg, G & Koch, J 2009, 'Organizational path dependence: opening the black box', The Academy of Management Review, vol. 34, no. 4, p. 21.

Talaue-McManus, L 2010, 'Examining human impacts on global biogeochemical cycling via the coastal zone and ocean margins', in K-K Liu, L Atkinson, R Quiñones & L Talaue-McManus (eds), Carbon and nutrient fluxes in continental margins, Springer Berlin Heidelberg, pp. 497-514, DOI 10.1007/978-3-540-92735-8_9, <http://dx.doi.org/10.1007/978-3-540-92735-8_9
http://link.springer.com/chapter/10.1007%2F978-3-540-92735-8_9>.

Tamba, IM & Cipta, IW 2011, 'Analisis partisipasi masyarakat dalam program pengentasan kemiskinan masyarakat pesisir di Karangasem, Bali', Jurnal Agrimeta, vol. 1, no. 2.

Taruc, SAK 2011, 'Resilience studies of an Indonesian coral reef: Ecological and social assessments in Karimunjawa National Park', MPhil thesis, The University of Queensland, <http://espace.library.uq.edu.au/view/UQ:242496>.

The World Bank 2012, BLT temporary unconditional cash transfer. Social assistance program and public expenditure review 2, 67342, The World Bank, <http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2012/03/06/000333037_20120306001405/Rendered/PDF/673240WP0BLT0T00Box367866B00PUBLIC0.pdf>.

TNP2K 2011, Pendataan rumah tangga miskin di wilayah pesisir/nelayan, Presentation slide, The National Team for the Accelleration of Poverty Reduction (TNP2K), Jakarta.

Tonts, M, Plummer, P & Argent, N 2014, 'Path dependence, resilience and the evolution of new rural economies: perspectives from rural Western Australia', Journal of Rural Studies, vol. 36, pp. 362-75.

Treffny, R & Beilin, R 2011, 'Gaining legitimacy and losing trust: stakeholder participation in ecological risk assessment for marine protected area management', Environmental Values, vol. 20, no. 3, pp. 417-38.

Turner, BL, 2nd, Kasperson, RE, Matson, PA, McCarthy, JJ, Corell, RW, Christensen, L, Eckley, N, Kasperson, JX, Luers, A, Martello, ML, Polsky, C, Pulsipher, A & Schiller, A 2003, 'A framework for vulnerability analysis in sustainability science', Proc Natl Acad Sci U S A, vol. 100, no. 14, pp. 8074-9.

Turner, BL, 2nd, Matson, PA, McCarthy, JJ, Corell, RW, Christensen, L, Eckley, N, Hovelsrud-Broda, GK, Kasperson, JX, Kasperson, RE, Luers, A, Martello, ML, Mathiesen, S, Naylor, R, Polsky, C, Pulsipher, A, Schiller, A, Selin, H & Tyler, N 2003, 'Illustrating the coupled human-environment system for vulnerability analysis: three case studies', Proc Natl Acad Sci U S A, vol. 100, no. 14, pp. 8080-5.

Turner, R, Cakacaka, A, Graham, N, Polunin, N, Pratchett, M, Stead, S & Wilson, S 2007, 'Declining reliance on marine resources in remote South Pacific societies: ecological versus socio-economic drivers', Coral Reefs, vol. 26, no. 4, pp. 997-1008.

van Amstel, M, de Neve, W, de Kraker, J & Glasbergen, P 2007, 'Assessment of the potential of ecolabels to promote agrobiodiversity', Ambio, vol. 36, no. 7, pp. 551-8.

Varkey, DA, Ainsworth, CH, Pitcher, TJ, Goram, Y & Sumaila, R 2010, 'Illegal, unreported and unregulated fisheries catch in Raja Ampat Regency, Eastern Indonesia', Marine Policy, vol. 34, no. 2, pp. 228-36.

Vergne, J-P & Durand, R 2010, 'The missing link between the theory and empirics of path dependence: conceptual clarification, testability issue, and methodological implications', Journal of Management Studies, vol. 47, no. 4, pp. 736-59.

Veríssimo, D 2013, 'Influencing human behaviour: an underutilised tool for biodiversity management', Conservation Evidence, vol. 10, no. 1, pp. 29-31.

Viswanathan, KK, Abdullah, NMR, Susilowati, I, Siason, IM & Ticao, C 1997, Enforcement and Compliance with Fisheries Regulations in Malaysia, Indonesia and the Philippines, Fisheries Co-Management Research Project, International Center for Living Aqautic Resources Management (ICLARM), Makati City, Philippines.

Vollan, B & Ostrom, E 2010, 'Social science: cooperation and the commons', Science, vol. 330, no. 6006, pp. 923-4.

Walker, B, Gunderson, L, Kinzig, A, Folke, C, Carpenter, S & Schultz, L 2006, 'A handful of heuristics and some propositions for understanding resilience in social-ecological systems', Ecology and Society, vol. 11, no. 1, p. 13.

Walker, B, Holling, C, Carpenter, S & Kinzig, A 2004, 'Resilience, adaptability and transformability in social-ecological Systems', Ecology and Society, vol. 9, no. 2, p. 5.

Walker, B & Meyers, JA 2004, 'Thresholds in ecological and social–ecological systems: a developing database', Ecology and Society, vol. 9, no. 2, p. 3.

Walker, B, Salt, D & Reid, W 2006, Resilience thinking: sustaining ecosystems and people in a changing world, Island Press, Washington DC.

Weeratunge, N, Béné, C, Siriwardane, R, Charles, A, Johnson, D, Allison, EH, Nayak, PK & Badjeck, M-C 2013, 'Small-scale fisheries through the wellbeing lens', Fish and Fisheries, vol. 15, no. 2, p. 25.

Weiss, K, Hamann, M, Kinney, M & Marsh, H 2012, 'Knowledge exchange and policy influence in a marine resource governance network', Global Environmental Change, vol. 22, no. 1, pp. 178-88.

West, JM & Salm, RV 2003, 'Resistance and resilience to coral bleaching: Implications for coral reef conservation and management', Conservation Biology, vol. 17, no. 4, pp. 956-67.

White, A, Christie, P, D'Agnes, H, Lowry, K & Milne, N 2005, 'Designing ICM projects for sustainability: lessons from the Philippines and Indonesia', Ocean and Coastal Management, vol. 48, no. 3-6, pp. 271-96.

White, WT, Last, PR, Dharmadi, Faizah, R, Chodrijah, U, Prisantoso, BI, Pogonoski, JJ, Puckridge, M & Blaber, SJM 2013, Market fishes of Indonesia (= Jenis-jenis ikan di Indonesia), Australian Centre for International Agricultural Research, Canberra.

Whitney, CK, Bennett, NJ, Ban, NC, Allison, EH, Armitage, D, Blythe, JL, Burt, JM, Cheung, W, Finkbeiner, EM, Kaplan-Hallam, M, Perry, I, Turner, NJ & Yumagulova, L 2017, 'Adaptive capacity: from assessment to action in coastal social-ecological systems', Ecology and Society, vol. 22, no. 2.

Widianarko, B, Verweij, RA, Van Gestel, CA & Van Straalen, NM 2000, 'Spatial distribution of trace metals in sediments from urban streams of Semarang, Central Java, Indonesia', Ecotoxicol Environ Saf, vol. 46, no. 1, pp. 95-100.

Wilkinson, C & Salvat, B 2012, 'Coastal resource degradation in the tropics: does the tragedy of the commons apply for coral reefs, mangrove forests and seagrass beds', Mar Pollut Bull, vol. 64, no. 6, pp. 1096-105.

William W. L. Cheung, VWYLaDP 2008, Modelling Present and Climate-Shifted Distribution of Marine Fishes and Invertebrates, 1198-6727, The Fisheries Centre, University of British Columbia, Vancouver.

Williams, B & Hummelbrunner, R 2007, Systems concepts in evaluation: a practitioner's toolkit, Stanford University Press, Stanford, CA.

Williams, BK & Brown, ED 2014, 'Adaptive management: from more talk to real action', Environmental Management, vol. 53, no. 2, pp. 465-79.

Winter, SC & May, PJ 2001, 'Motivation for compliance with environmental regulations', Journal of Policy Analysis and Management, vol. 20, no. 4, pp. 675-98.

Witt, U 2001, 'Learning to consume–A theory of wants and the growth of demand', Journal of Evolutionary Economics, vol. 11, no. 1, pp. 23-36.

Wong, PP 1998, 'Coastal tourism development in Southeast Asia: relevance and lessons for coastal zone management', Ocean & Coastal Management, vol. 38, no. 2, pp. 89-109.

Wood, SW & Bowman, DMJS 2011, 'Alternative stable states and the role of fire–vegetation–soil feedbacks in the temperate wilderness of southwest Tasmania', Landscape Ecology, vol. 27, no. 1, pp. 13-28.

Wooldridge, JM 2012, Introductory econometrics: a modern approach, 5th edn, South-Western College Pub, Mason.

World Bank 2008, Small-scale capture fisheries: a global overview with emphasis on developing countries, Worldbank, Washington DC, <http://documents.worldbank.org/curated/en/2008/09/18613098/small-scale-capture-fisheries-global-overview-emphasis-developing-countries>.

Worm, B, Barbier, EB. Beaumont, N, Duffy, J.E., Folke, C, Halpern, BS, Jackson, JB, Lotze, HK, Micheli, F, Palumbi, SR and Sala, E, Selkoe KA, Stachowicz JJ, Watson R, 2006. 'Impacts of biodiversity loss on ocean ecosystem services', Science, vol. 314, no. 5800, pp.787-790.

Wright, C 2012, 'Multiple systems thinking methods for resilience research', MPhil thesis, Cardiff University, <http://orca.cf.ac.uk/45395/>.

Xu, L, Marinova, D & Guo, X 2014, 'Resilience thinking: a renewed system approach for sustainability science', Sustainability Science, vol. 10, no. 1, pp. 123-38.

Yin, RK 2009, Case study research: design and methods, vol. 5., Sage Publications, Thousand Oaks, Calif.

Yuan, HP, Shen, LY, Hao, JJL & Lu, WS 2011, 'A model for cost–benefit analysis of construction and demolition waste management throughout the waste chain', Resources, Conservation and Recycling, vol. 55, no. 6, pp. 604-12.

Appendix 1. Ethics approval

THE UNIVERSITY OF QUEENSLAND

Institutional Human Research Ethics Approval

Project Title:	Capturing Coral Reef and Related Ecosystem Services (CCRES) Project
Chief Investigator:	Prof Peter Mumby, Dr Carl Smith, Ms Melanie King
Supervisor:	Dr Carl Smith, Prof Peter Mumby
Co-Investigator(s):	Prof Tom Baldock, Dr Dave Callaghan, Dr Behnan Shabani, Prof Andrew Griffith, Dr Russell Richards, Mr Siham Taruc, Dr Alice Rogers, Mr Nicholas Wolff, Prof Matthew Sanders, Mr John Pickering
School(s):	Biological Sciences; SAFS; Business; Civil Engineering; Psychology; Centre for Biodiversity and Conservation Science
Approval Number:	2015000582
Granting Agency/Degree:	The World Bank; Global Environment Facility; UQ
Duration:	31st December 2018

Comments/Conditions:

Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

Name of responsible Committee:
Behavioural & Social Sciences Ethical Review Committee
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:
Associate Professor John McLean
Chairperson
Behavioural & Social Sciences Ethical Review Committee

Signature JMcL Date 11/5/2015

Appendix 2. Participant recruitment documents used by the local collaborators consisted of the project information sheet and consent sheet each prepared in English and Bahasa Indonesia versions.

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

https://espace.library.uq.edu.au/view/UQ:a40c1f6/appendices.pdf

or obtained via email request to the author at: siham.afatta@uqconnect.edu.au

Appendix 3. Facilitator's script used in the problem scoping FGDs

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

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Appendix 4. Facilitator's script used in the first round of problem mapping FGDs

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

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Appendix 5. Facilitator's script used in Round Two of problem mapping FGDs

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Appendix 6. The SESAMME iPad application

The detailed description of the SESAMME iPad application can be found in:

Richards, R., Smith, C, Setianto, N.A. (2016). SESAMME: An iPad application for participatory systems modelling. System Dynamics Conference, Delft. Proceedings of the 34th International Conference of the System Dynamics Society, Delft, Netherlands -- July 17-21, 2016

Appendix 7. Participant data extracted from the problem scoping FGD attendance lists

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

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Appendix 8. Participant data extracted from the Round One problem mapping FGD attendance lists

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

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Appendix 9. Participant data extracted from the Round Two problem mapping FGD attendance lists

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

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Appendix 10. Visual materials developed in the problem scoping FGDs

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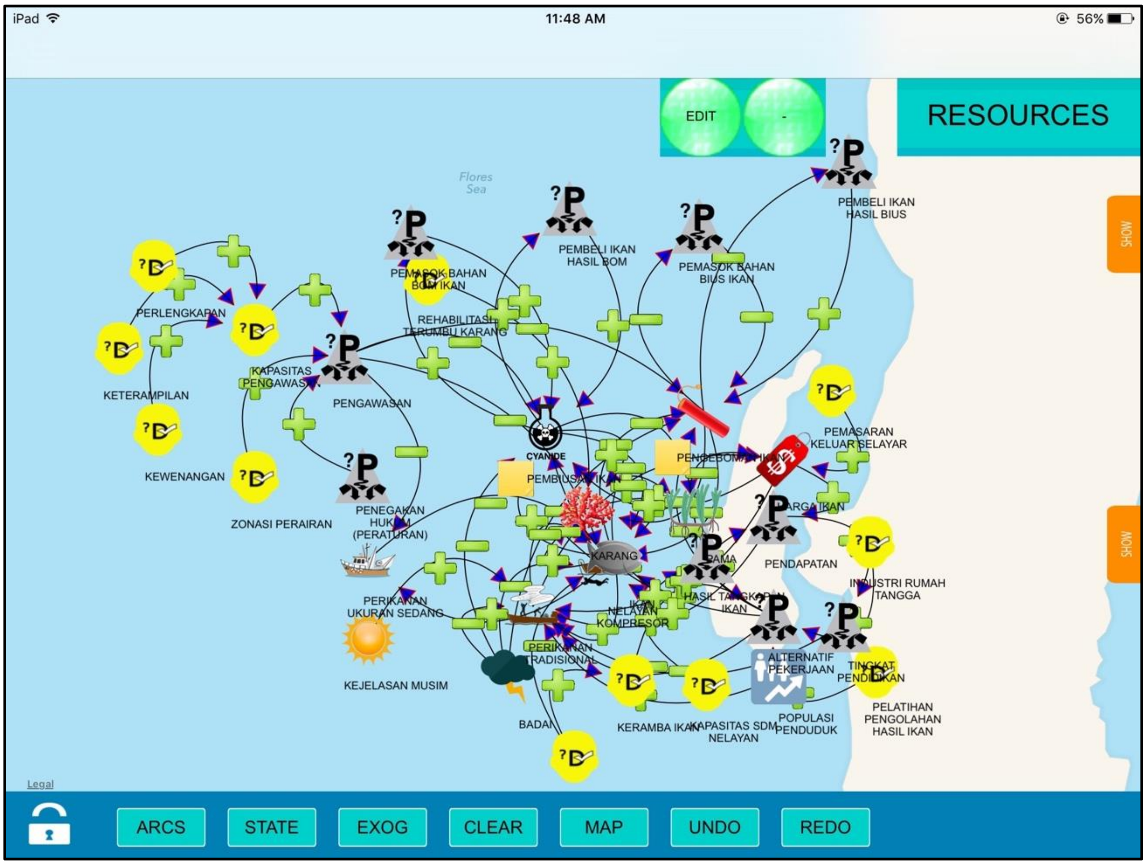
Appendix 11. SESAMME maps developed from each of the problem mapping FGDs

Each of the SESAMME maps presented below is produced in the second round of the problem mapping FGDs of the associated village. The SESAMME maps that selectively display a particular graphical element group can be obtained by email request to the author.

1. Final SESAMME map from the Round Two FGD in Kahu-kahu by Participant Group 1



Due to the PhD thesis word and page limit, the rest of the content of this appendix is available as a Portable Document Format that can be downloaded from:

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Appendix 12. Mental information about the system extracted from the SESAMME maps

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

https://espace.library.uq.edu.au/view/UQ:a40c1f6/appendices.pdf

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Appendix 13. Versions of CLD 1 developed using data from the Round One of the problem mapping FGDs

Diagram 1A. The detailed version of CLD 1 (Continued to Diagram 1B in the next page), which includes interactions between variables that has the highest percentage of occurrence in all FGDs (n=15, number in brackets).

Diagram 1B. The detailed version of CLD 1 (connected to Diagram 1A in the previous page)

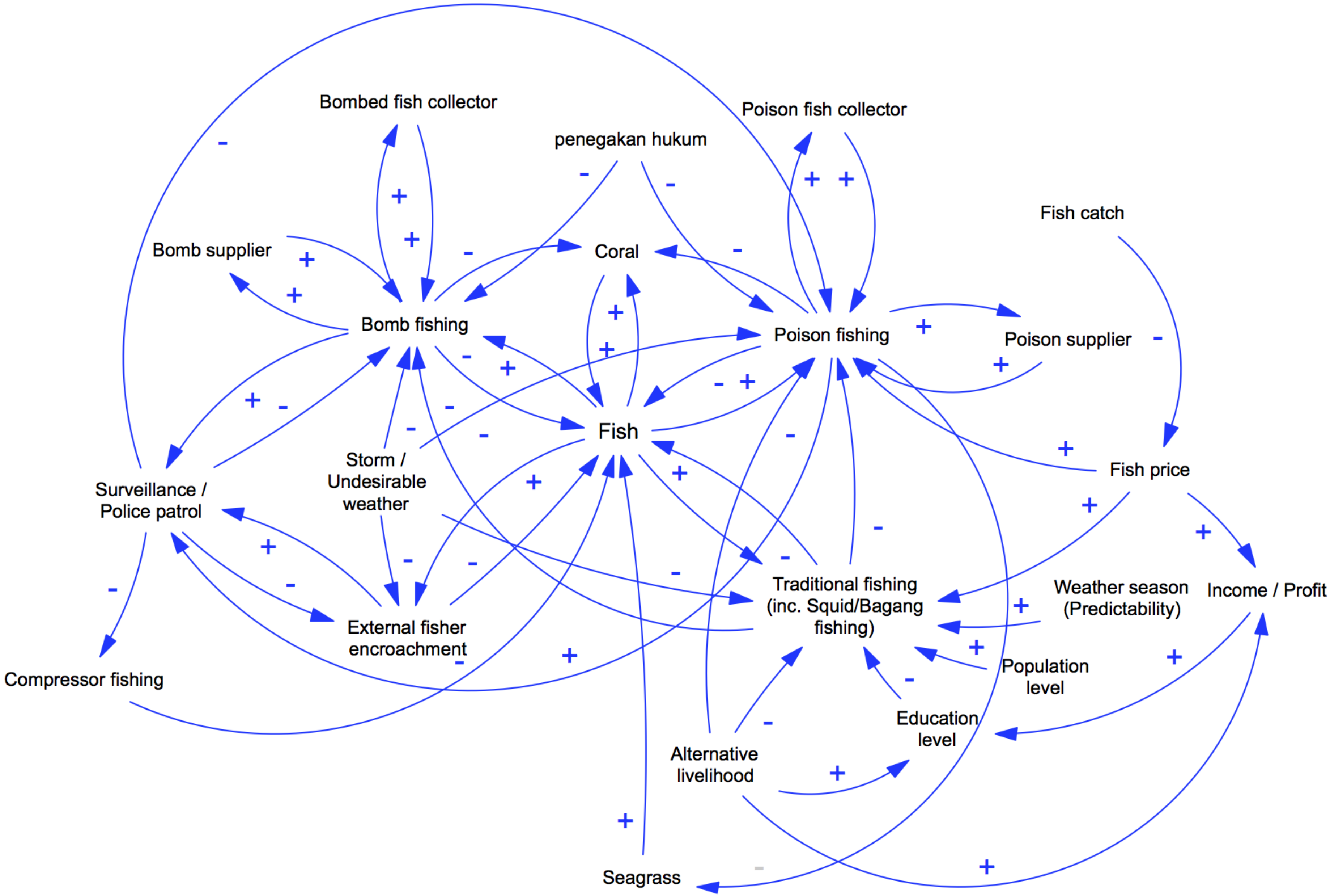
Due to the PhD thesis word and page limit, Diagram 1A and 1B are available as a Portable Document Format that can be downloaded from:

https://espace.library.uq.edu.au/view/UQ:a40c1f6/appendices.pdf

or obtained via email request to the author at:

siham.afatta@uqconnect.edu.au

Diagram 2. Simplified version of CLD 1



Appendix 14. The detailed version of CLD 2 developed using data from the Round Two of the problem mapping FGDs

Diagram 1A. The detailed version of CLD 2 (Connected to Diagram 1B in the next page)

Diagram 1B. The detailed version of CLD 2 (connected to Diagram 1A in the previous page)

Due to the PhD thesis word and page limit, Diagram 1A and 1B are available as a Portable Document Format that can be downloaded from:

https://espace.library.uq.edu.au/view/UQ:a40c1f6/appendices.pdf

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Appendix 15. Question route form used during the supplementary interview survey

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

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Appendix 16. Extracted information from the supplementary interview survey

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Appendix 17. Results of the secondary analysis of the Bio-LEWIE household survey dataset

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Appendix 18. The stock-and-flow diagram represented in the Stella® software

The SFDs are the version represented in the Stella® software. The Stella® equations embedded in each of the SFD building blocks are listed in Appendix 19 to Appendix 26, which contains equations in the converters, flows, stocks, graphical converter; input values of the initial stocks, constant converters, switches, and calibrators; in the respective order. In these appendices, equations are presented in the form of Stella® input syntax that follows the online software manual published by ISEE systems (https://www.iseesystems.com/help). Names of array dimensions or dimension element in the model descriptions refer to the description in Section 6.1.3 in the thesis body.

Due to the PhD thesis word and page limit, the descriptions for the SFDs presented below can be found in a Portable Document Format file that can be downloaded from:

https://espace.library.uq.edu.au/view/UQ:a40c1f6/appendices.pdf

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siham.afatta@uqconnect.edu.au

Sector 1: Seagrass and mangrove fish habitat condition

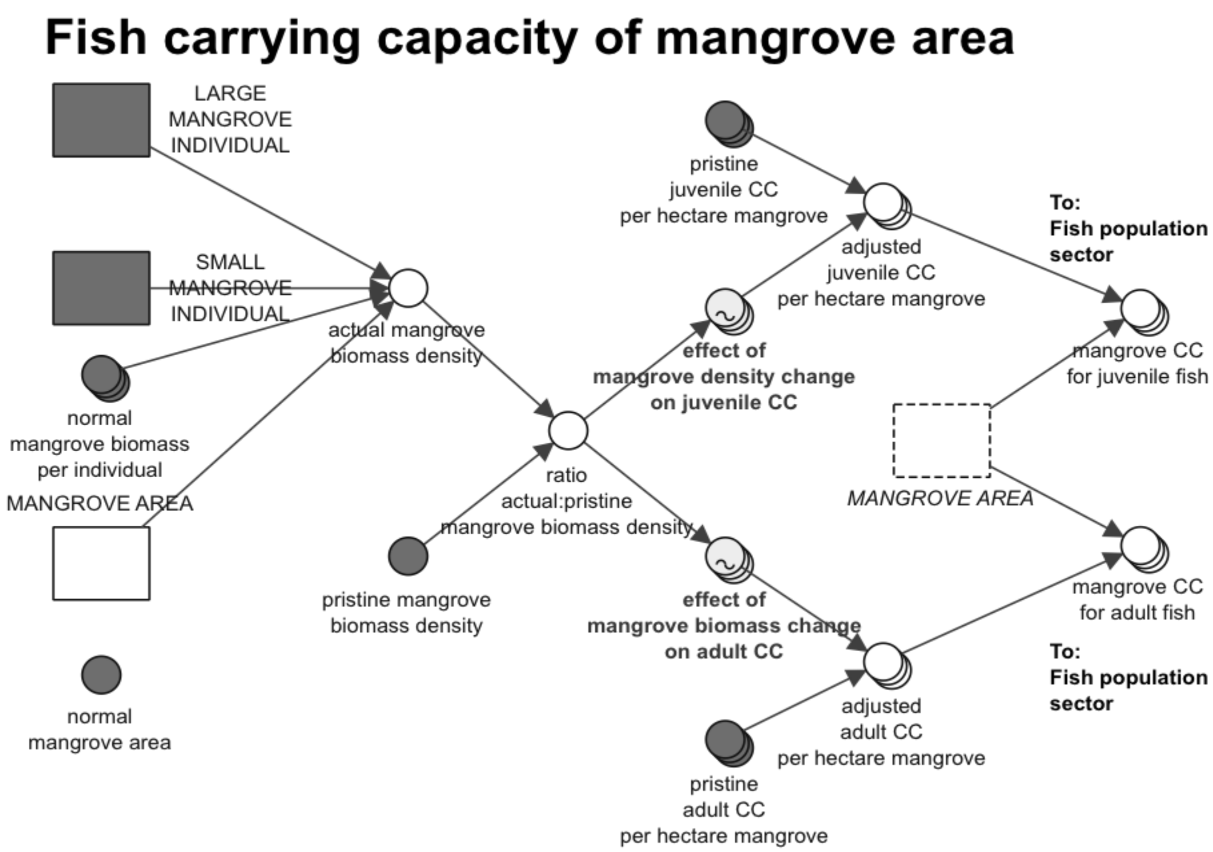


Figure 1-1. Segment 1-A

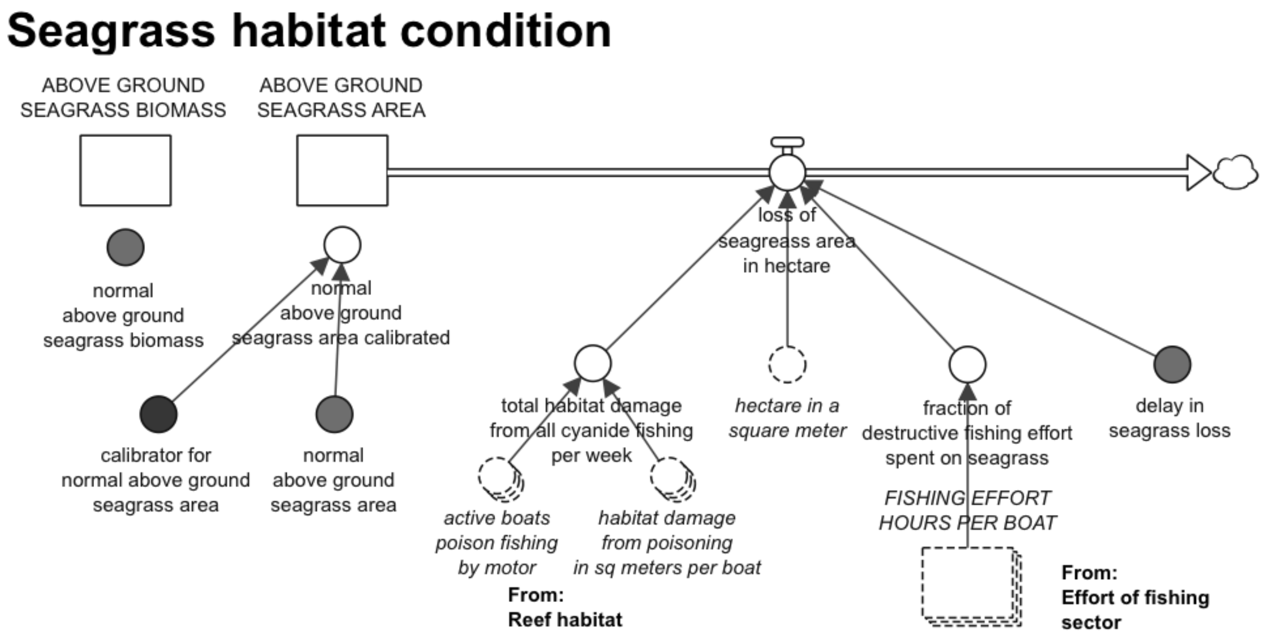


Figure 1-2. Segment 1-B

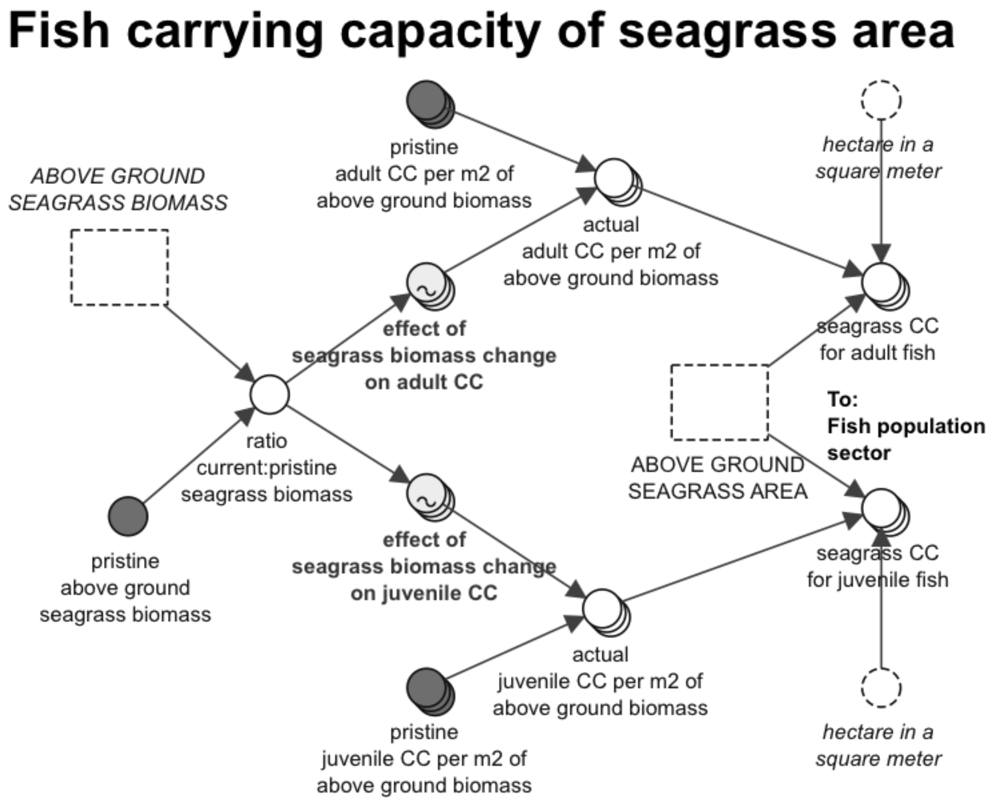


Figure 1-3. Segment 1-C

Sector 2: Coral reef fish habitat condition

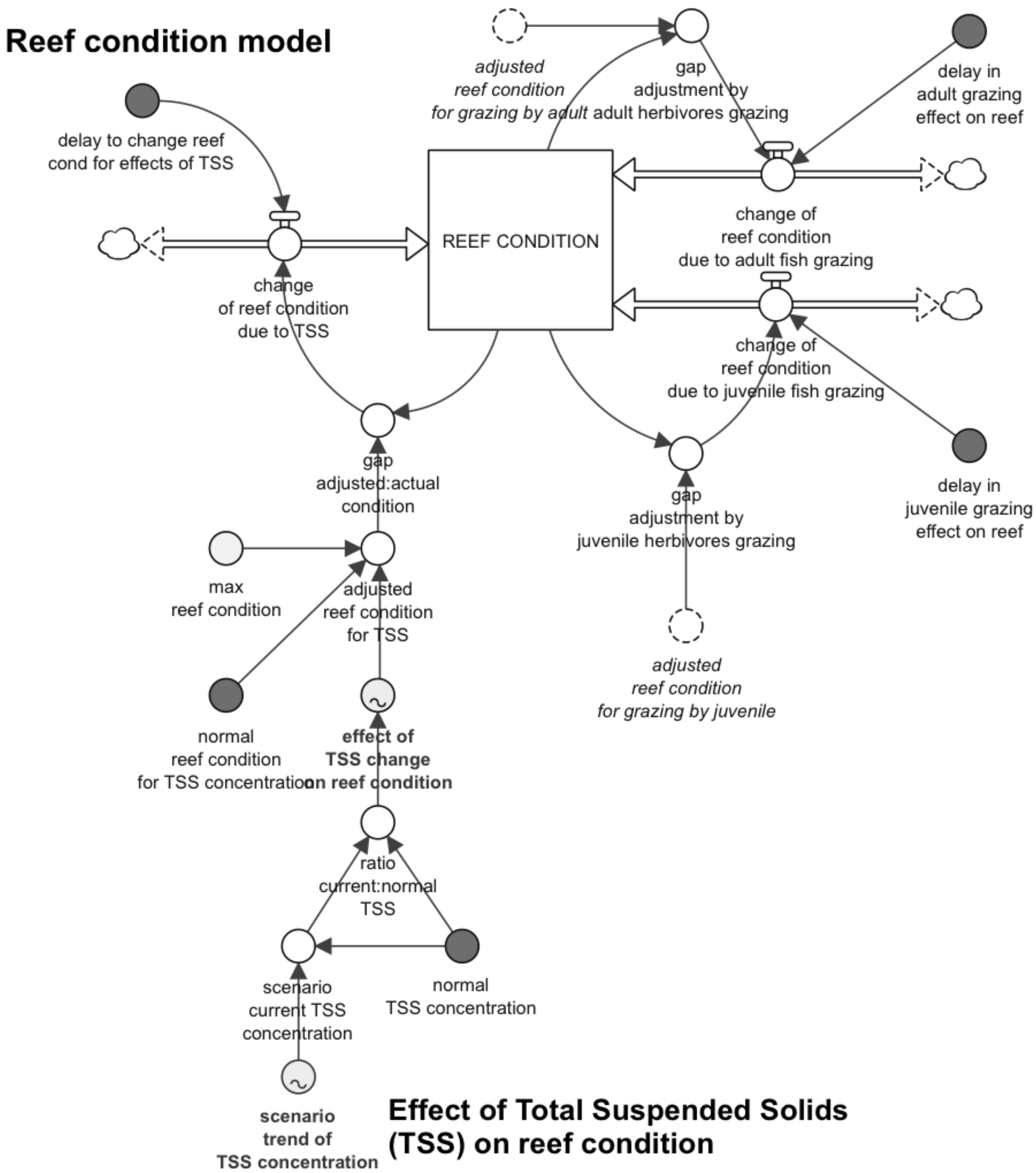


Figure 1-4. Segment 2-A

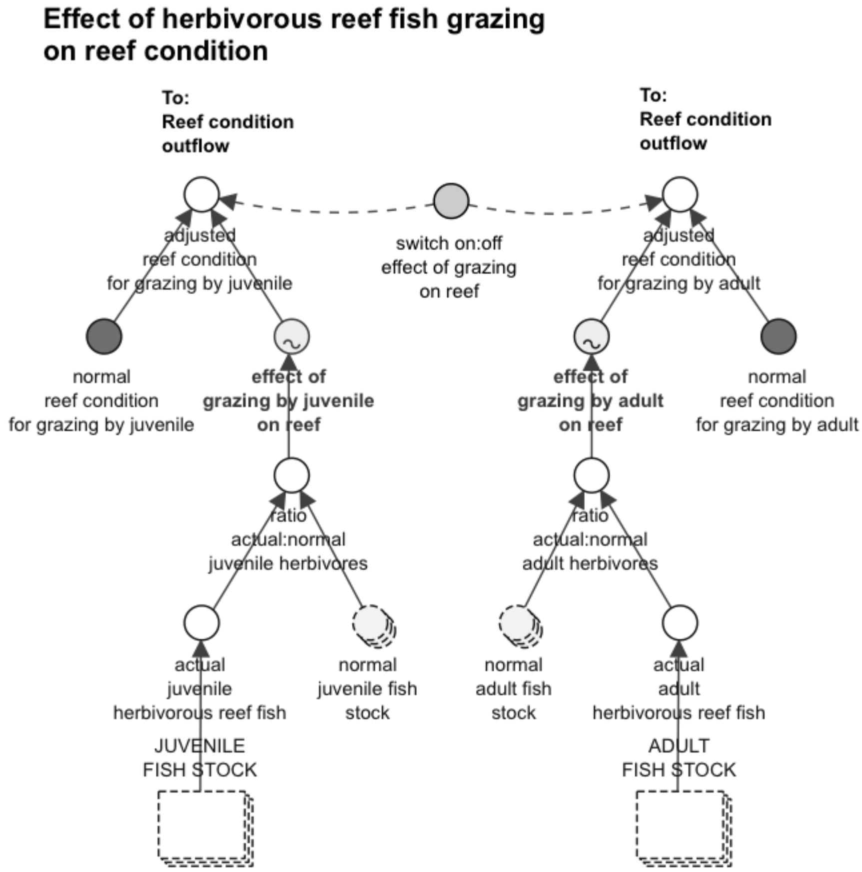


Figure 1-5. Segment 2-B

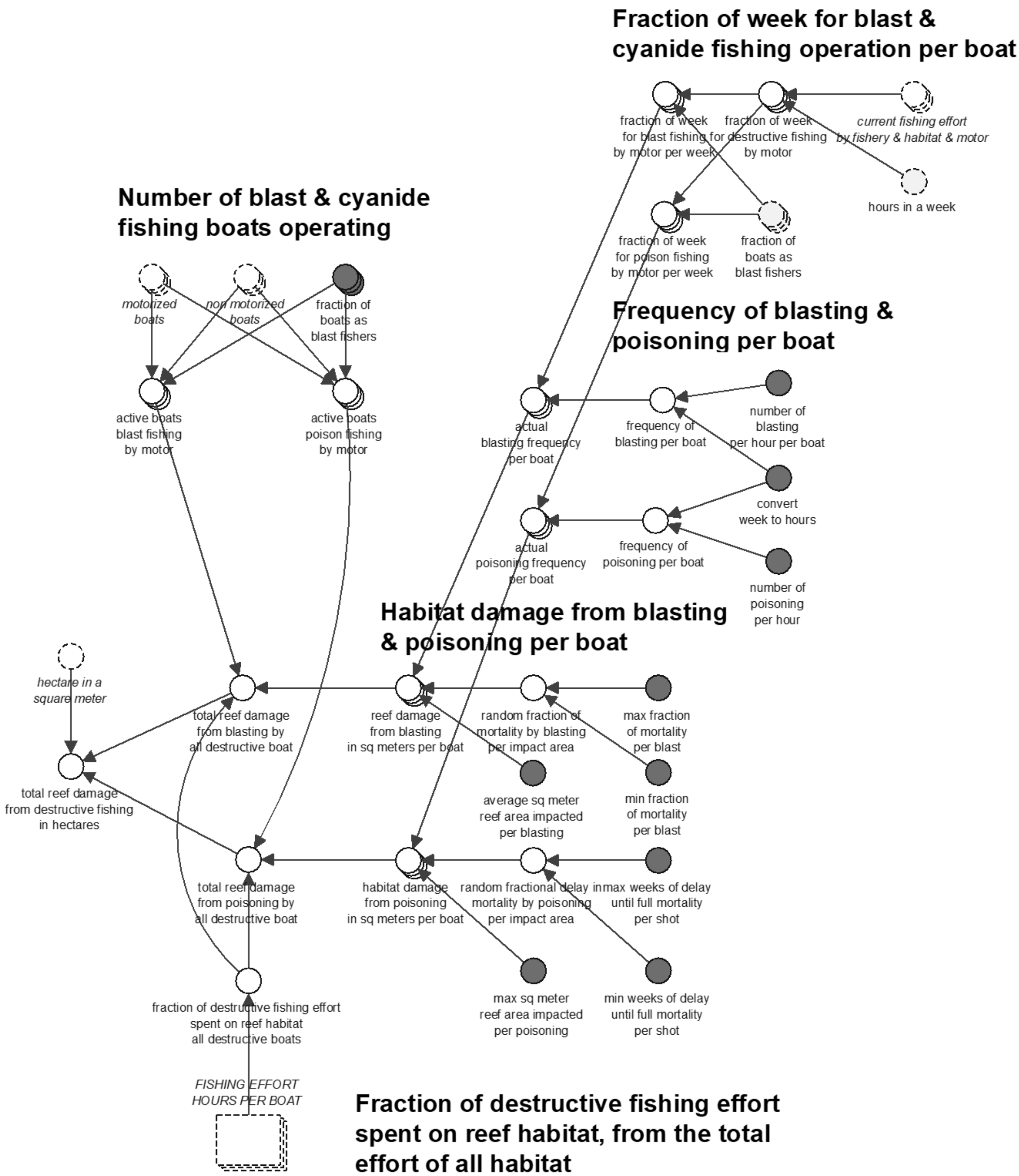


Figure 1-6. Segment 2-C

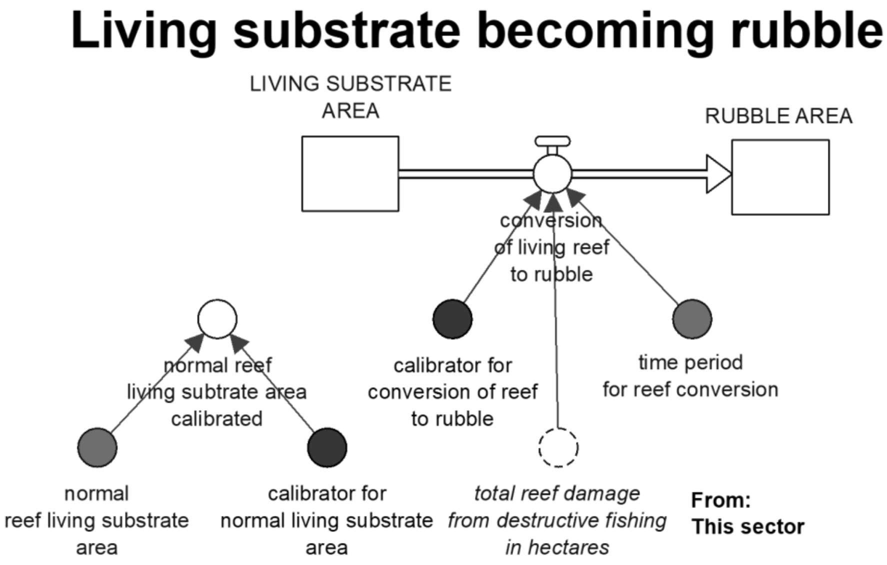


Figure 1-7. Segment 2-D

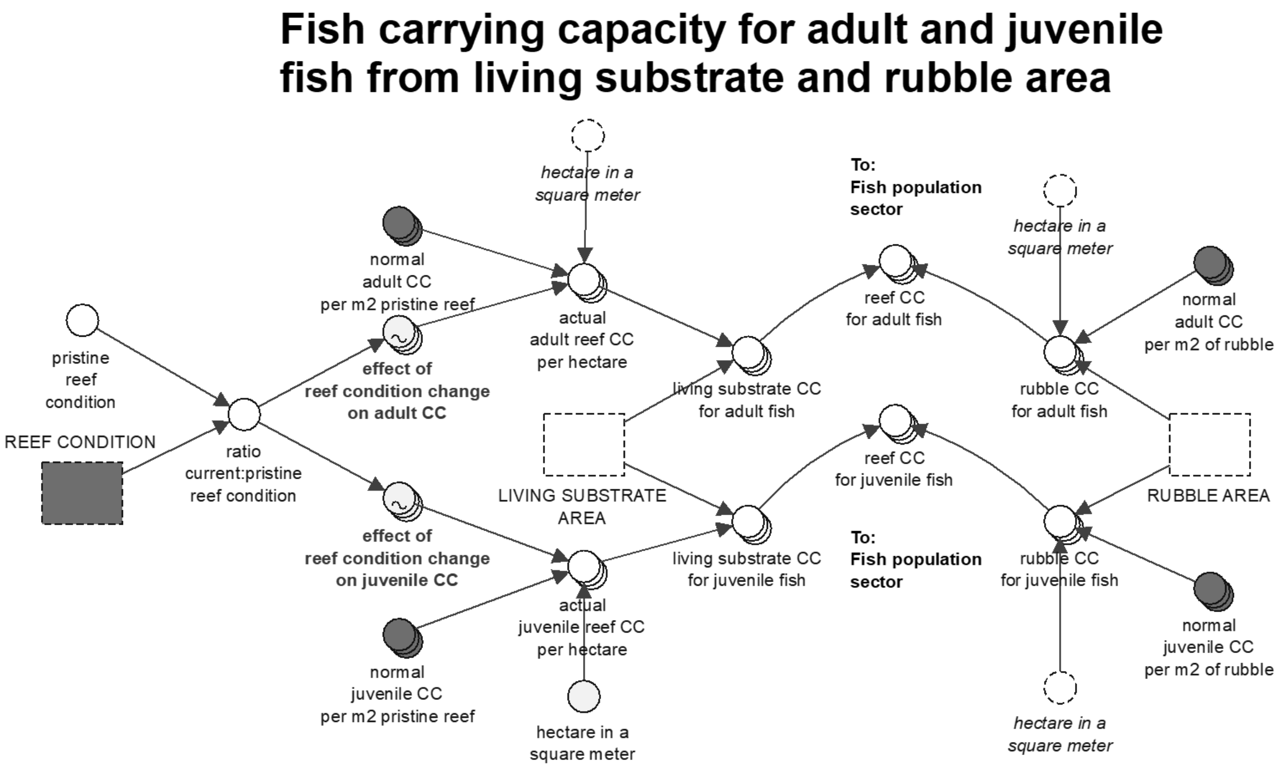


Figure 1-8. Segment 2-E

Sector 3: Fish population

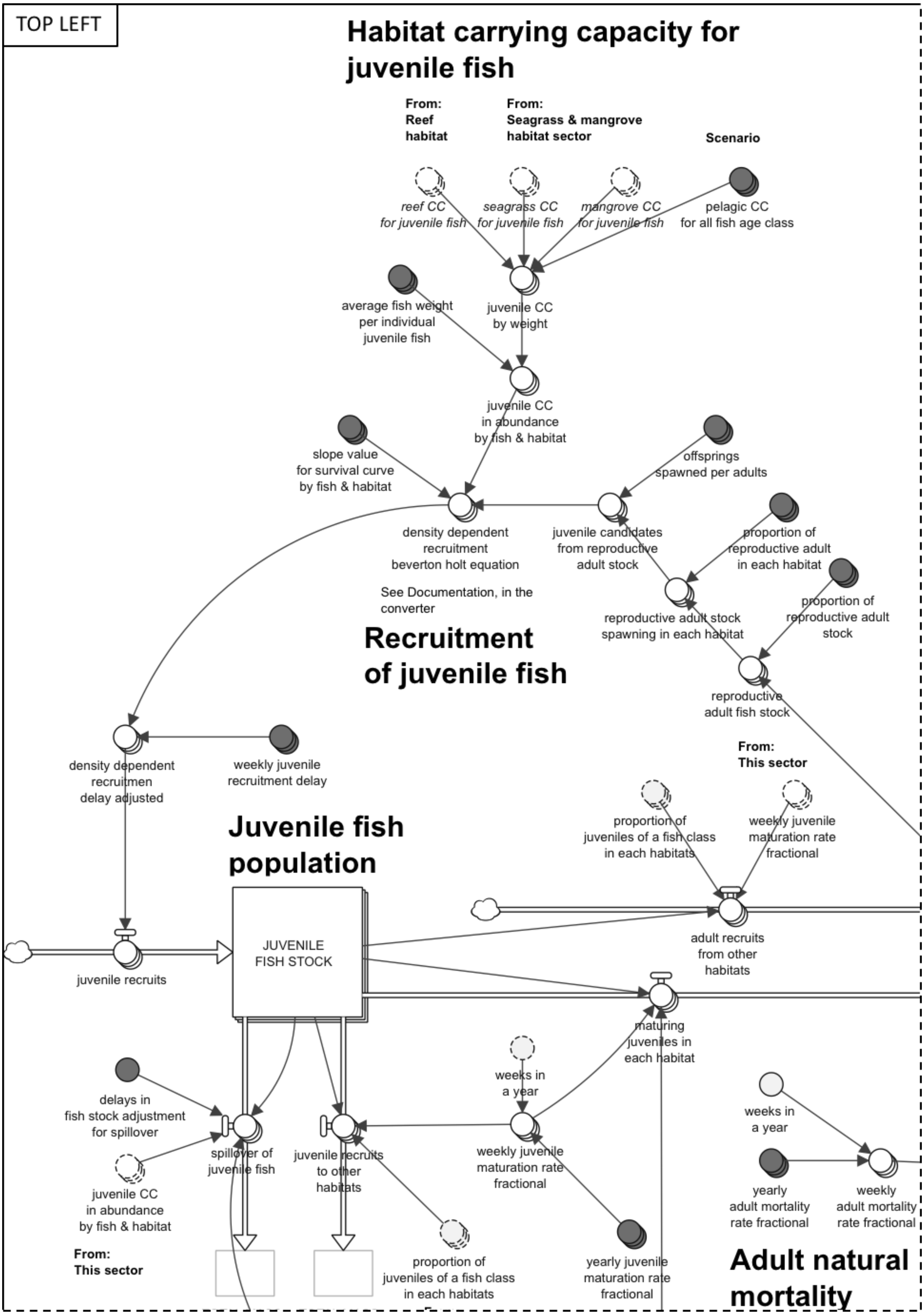


Figure 1-9. Top left

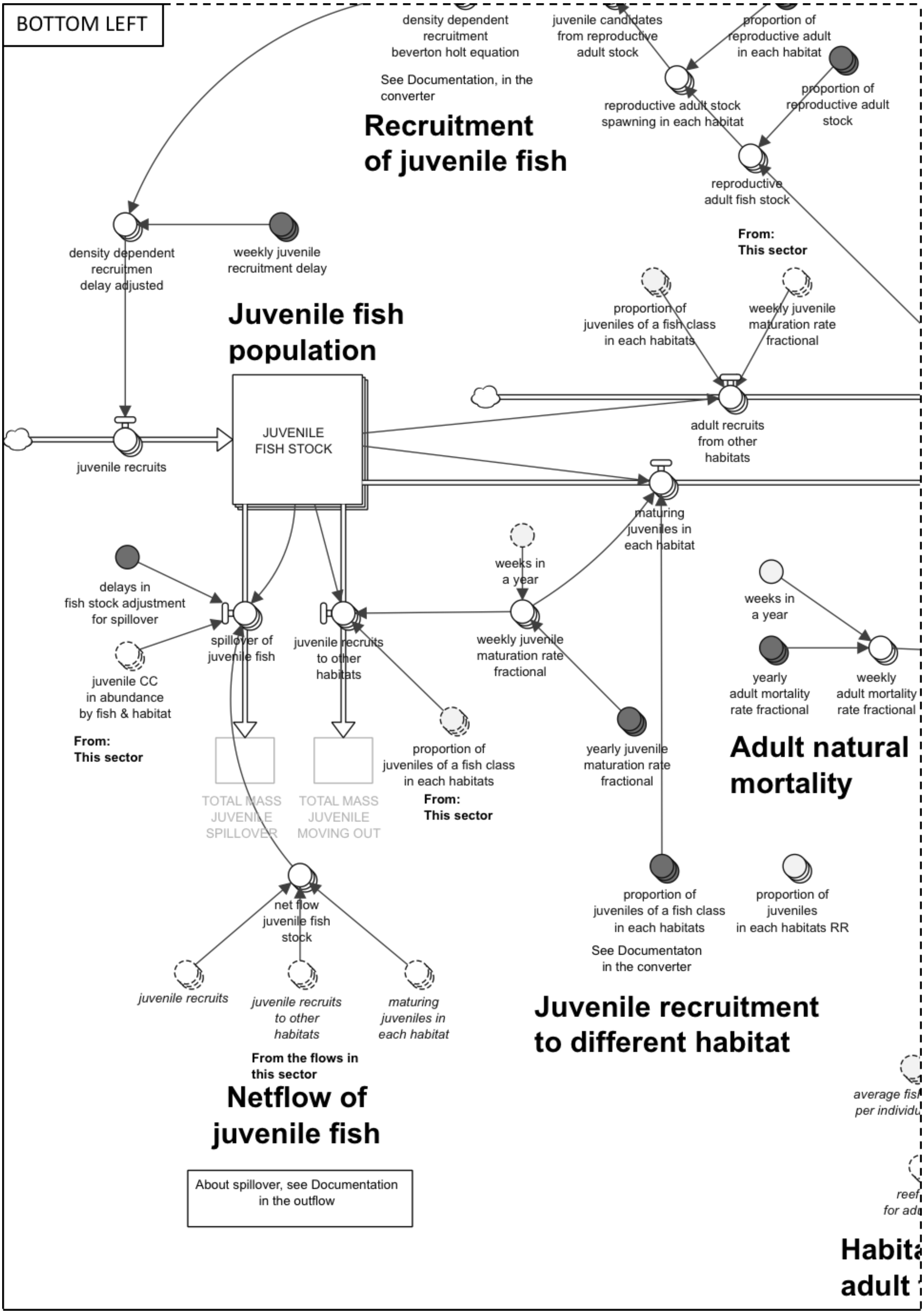


Figure 1-10. Bottom left

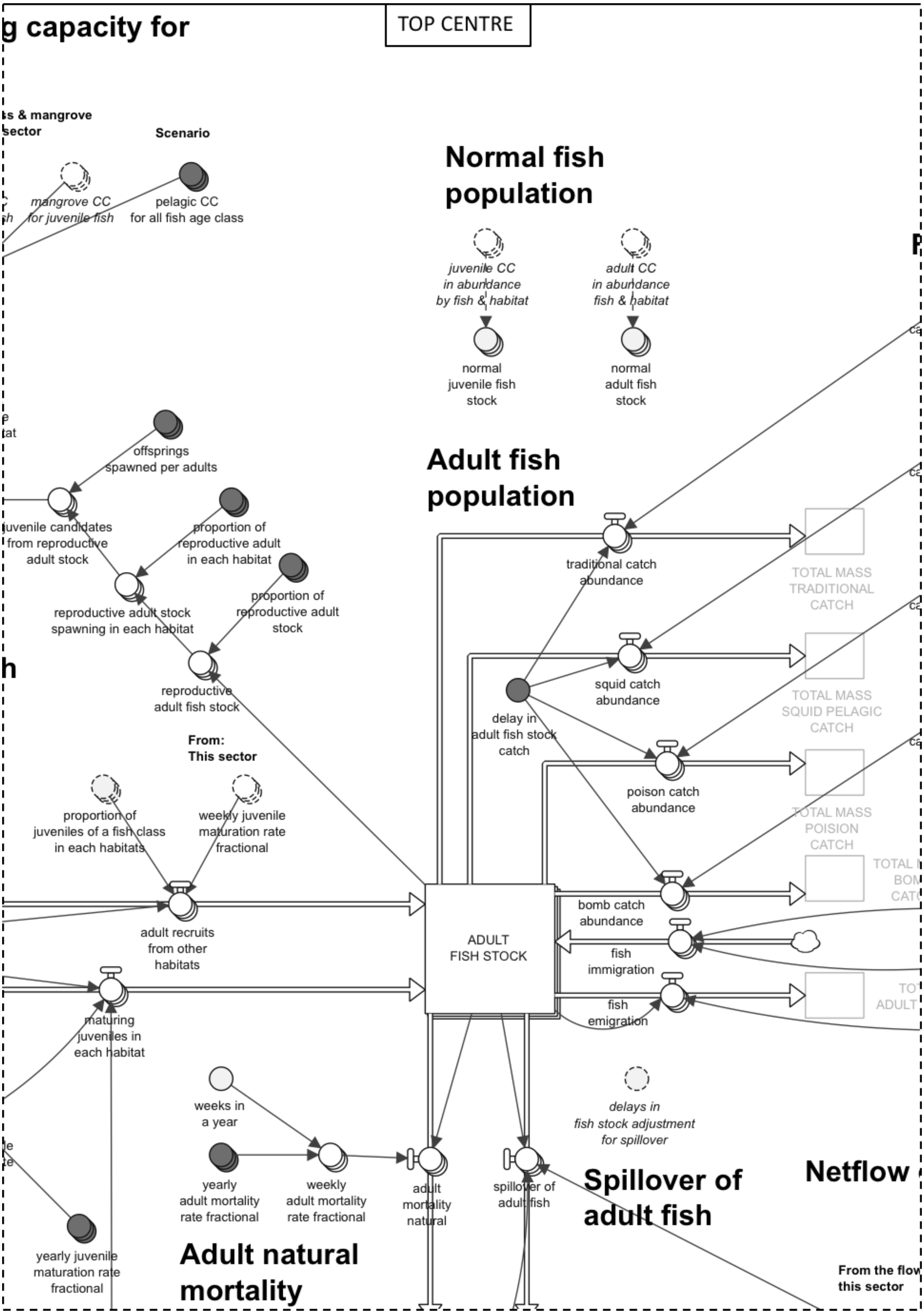


Figure 1-11. Top centre

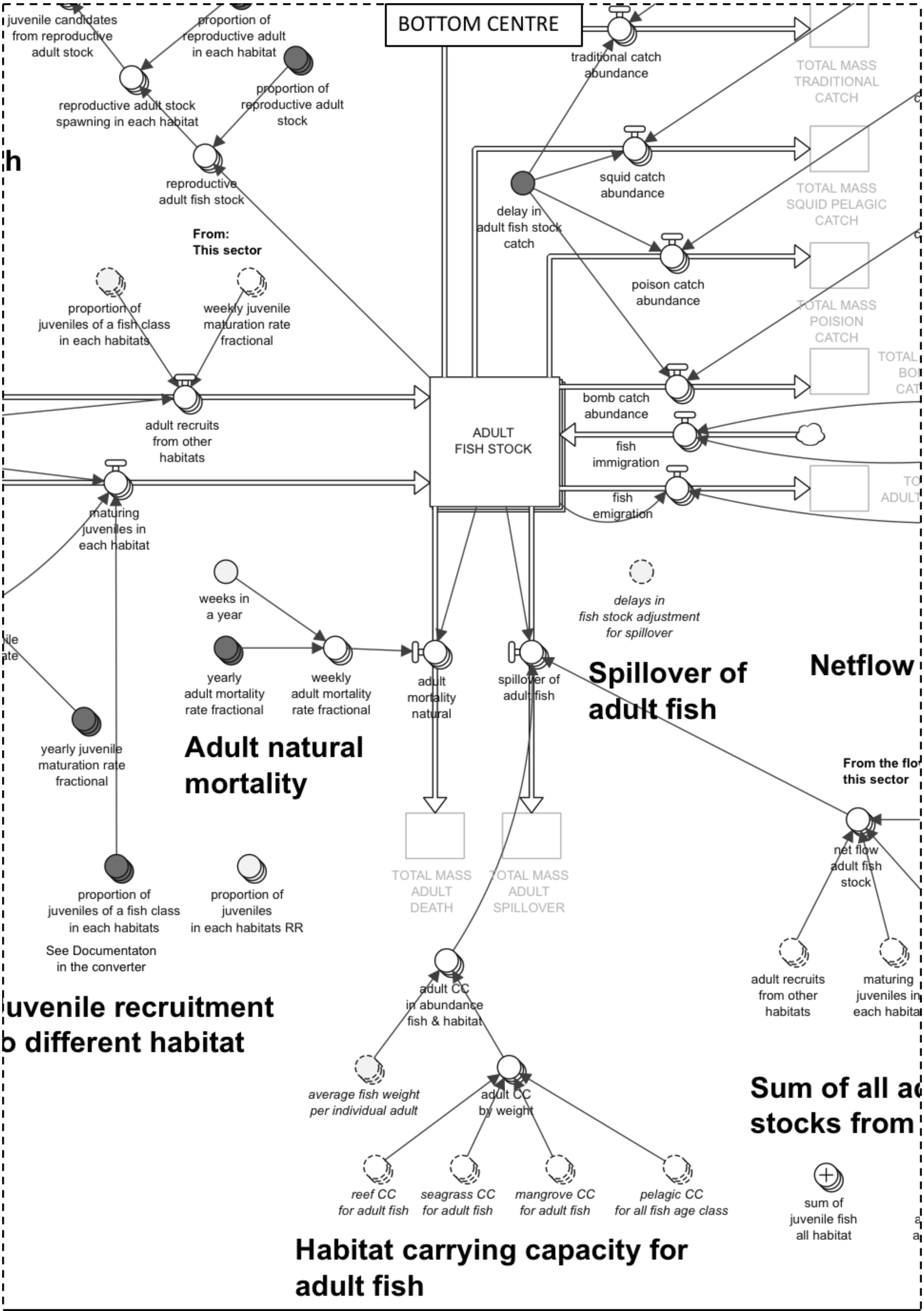


Figure 1-12. Bottom centre

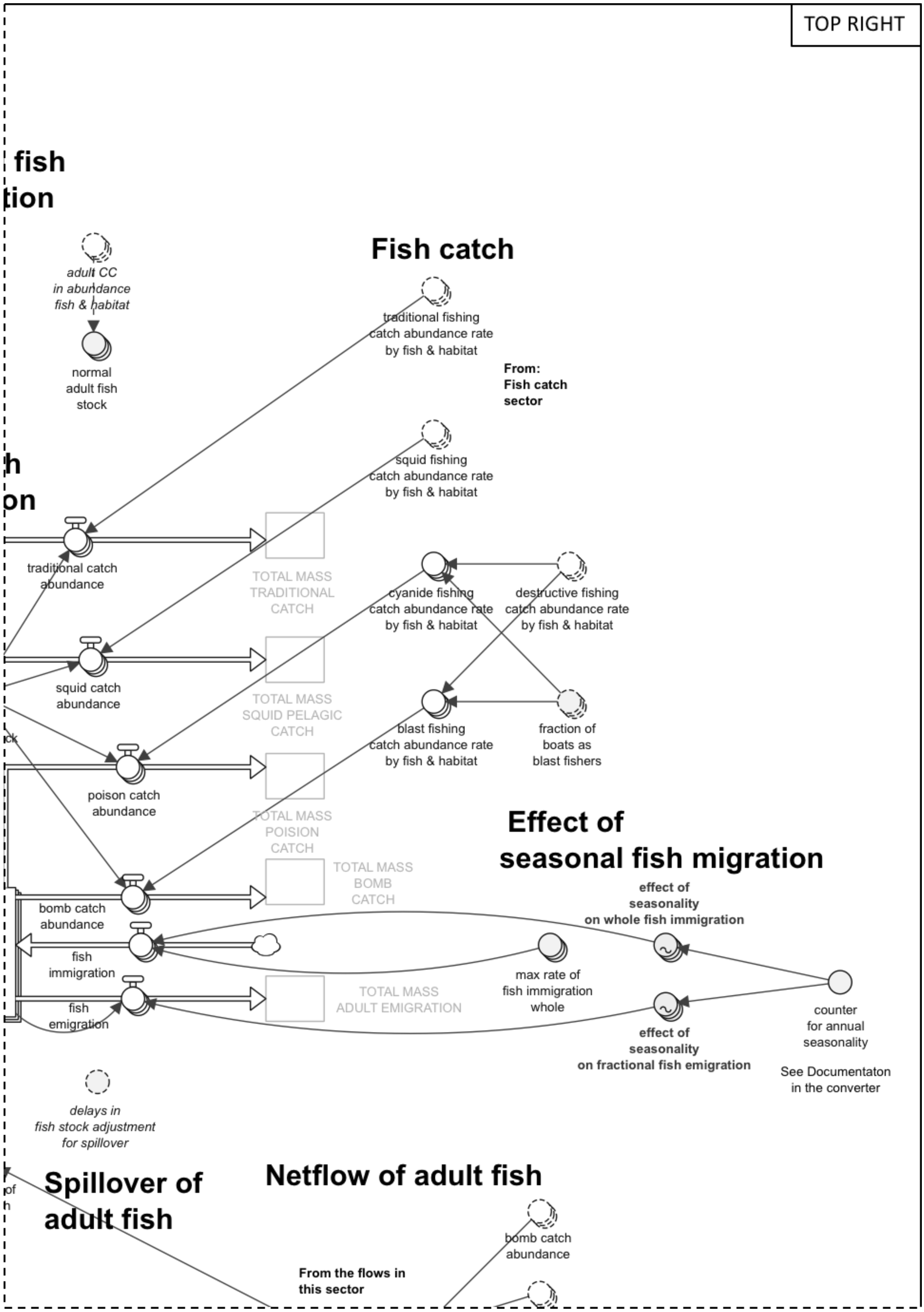


Figure 1-13. Top right

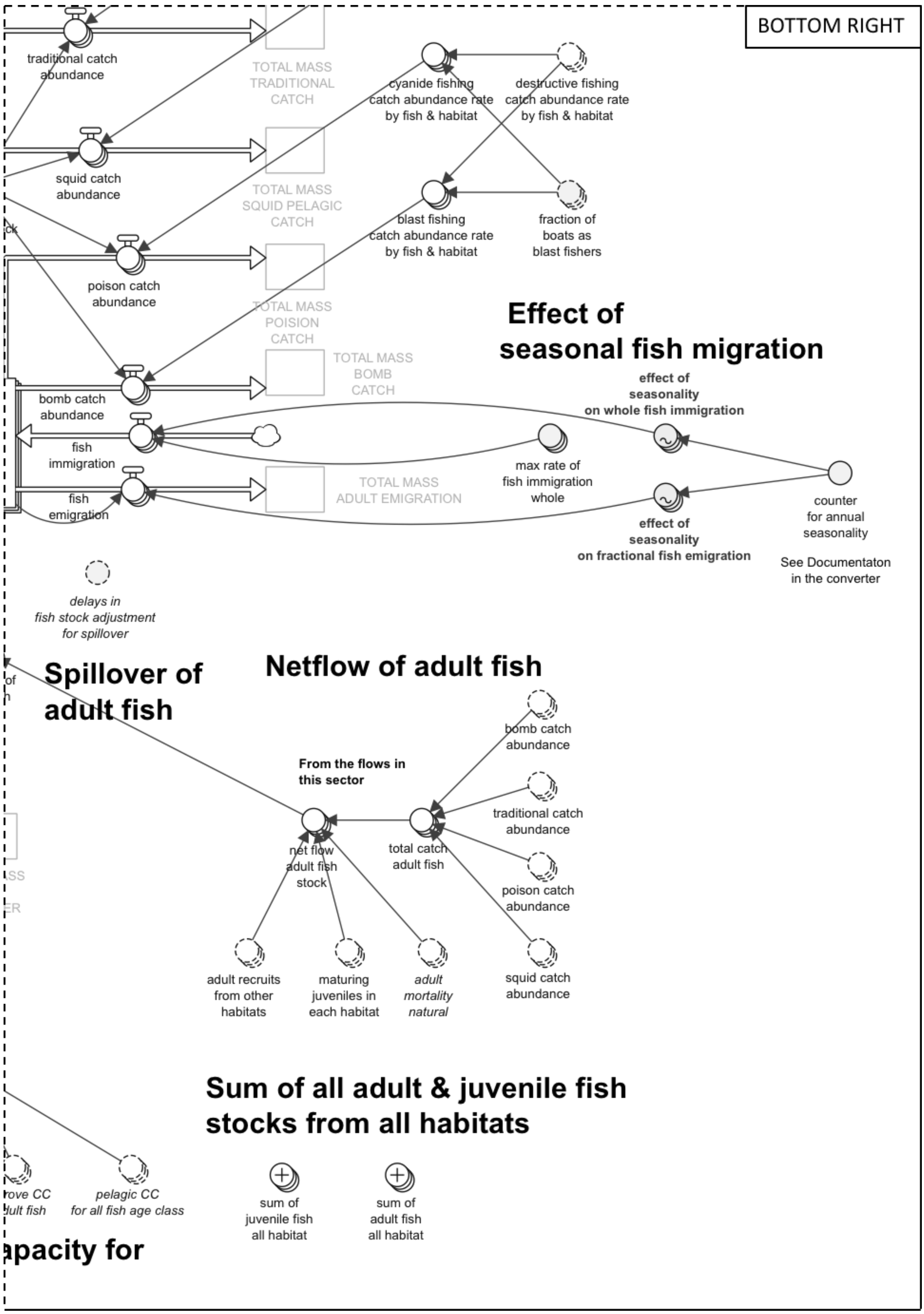


Figure 1-14. Bottom right

Sector 4: Fishing boat

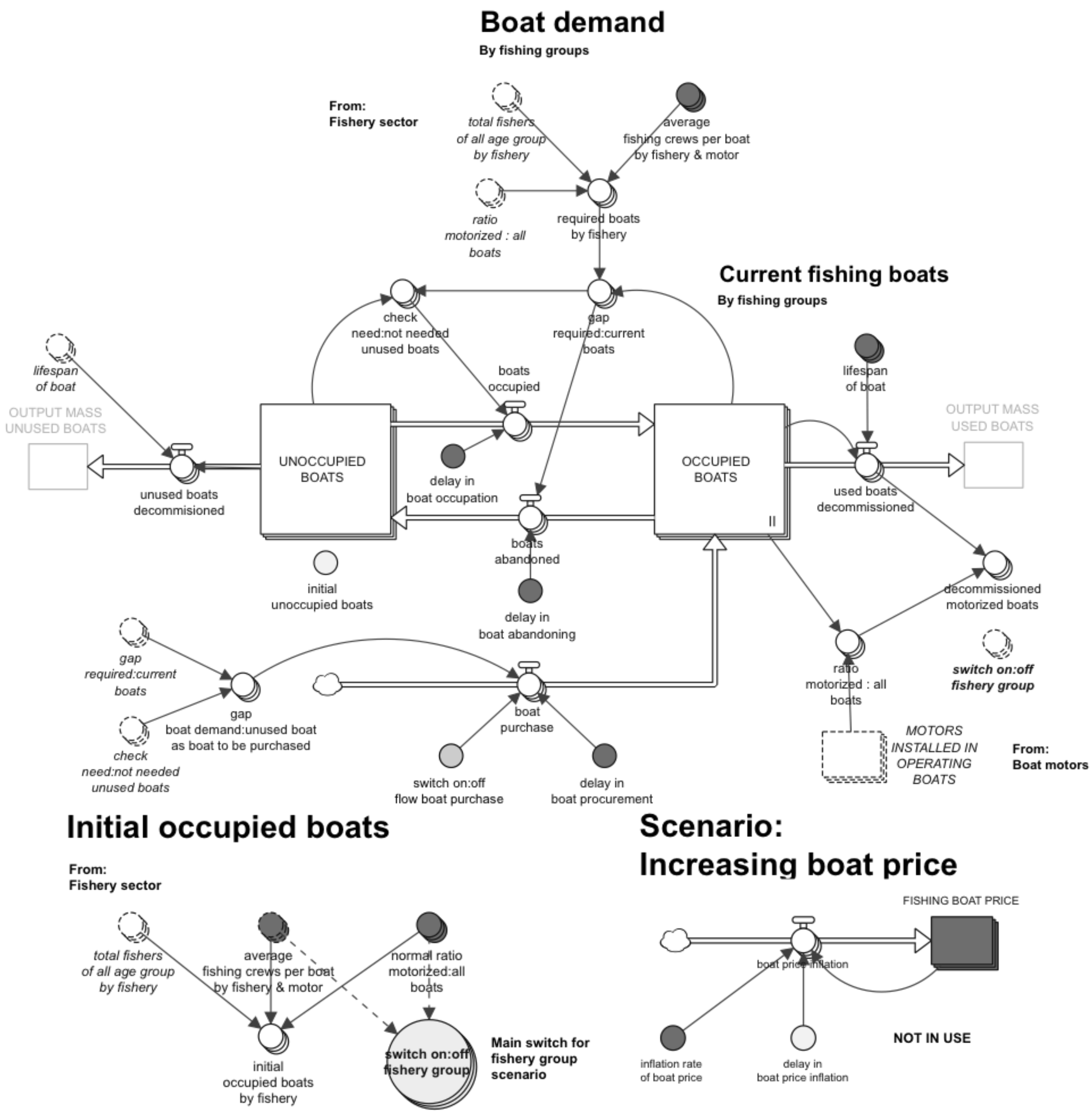


Figure 1-15. Segment 4-A

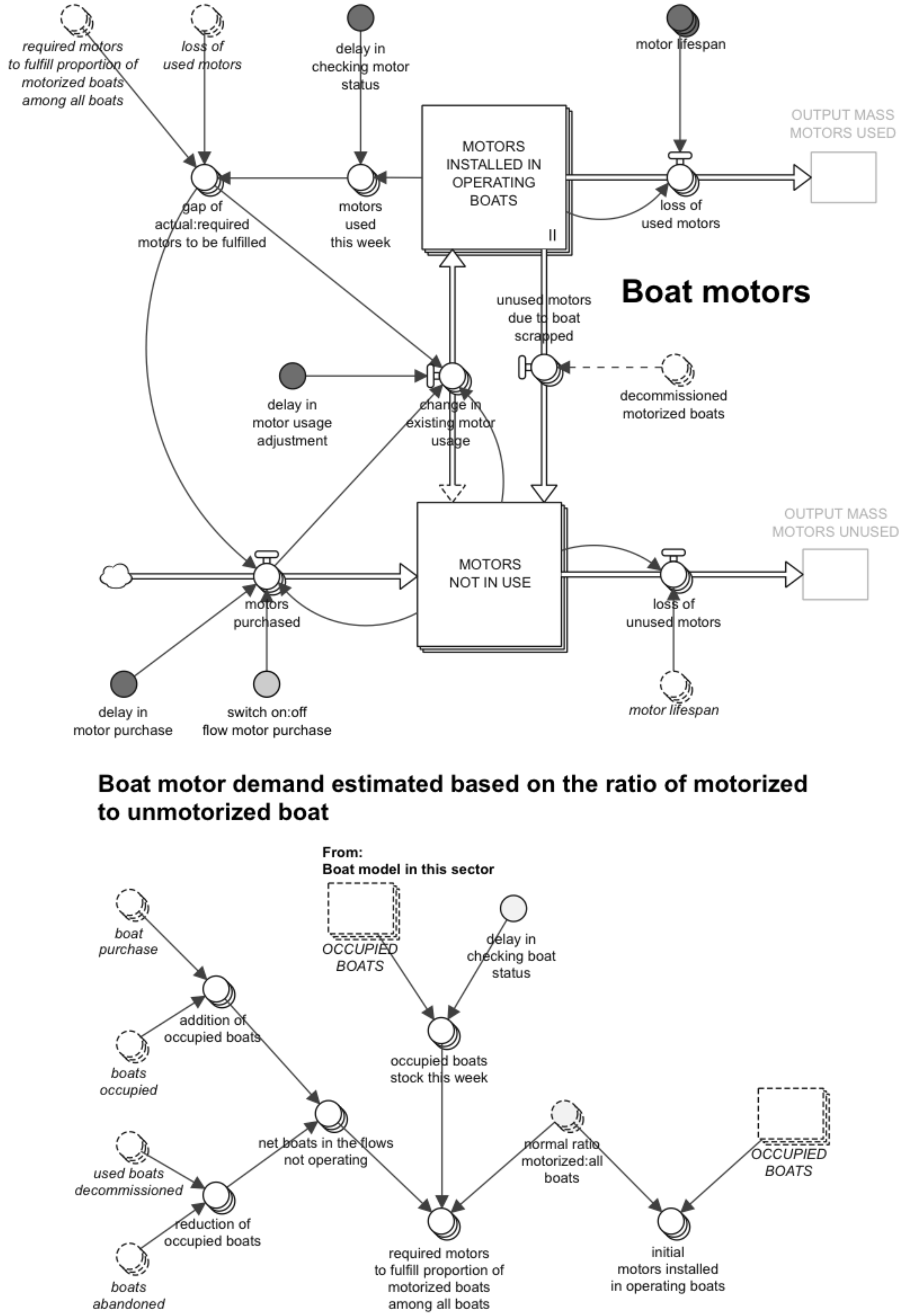


Figure 1-16. Segment 4-B

Sector 5: Fish catch

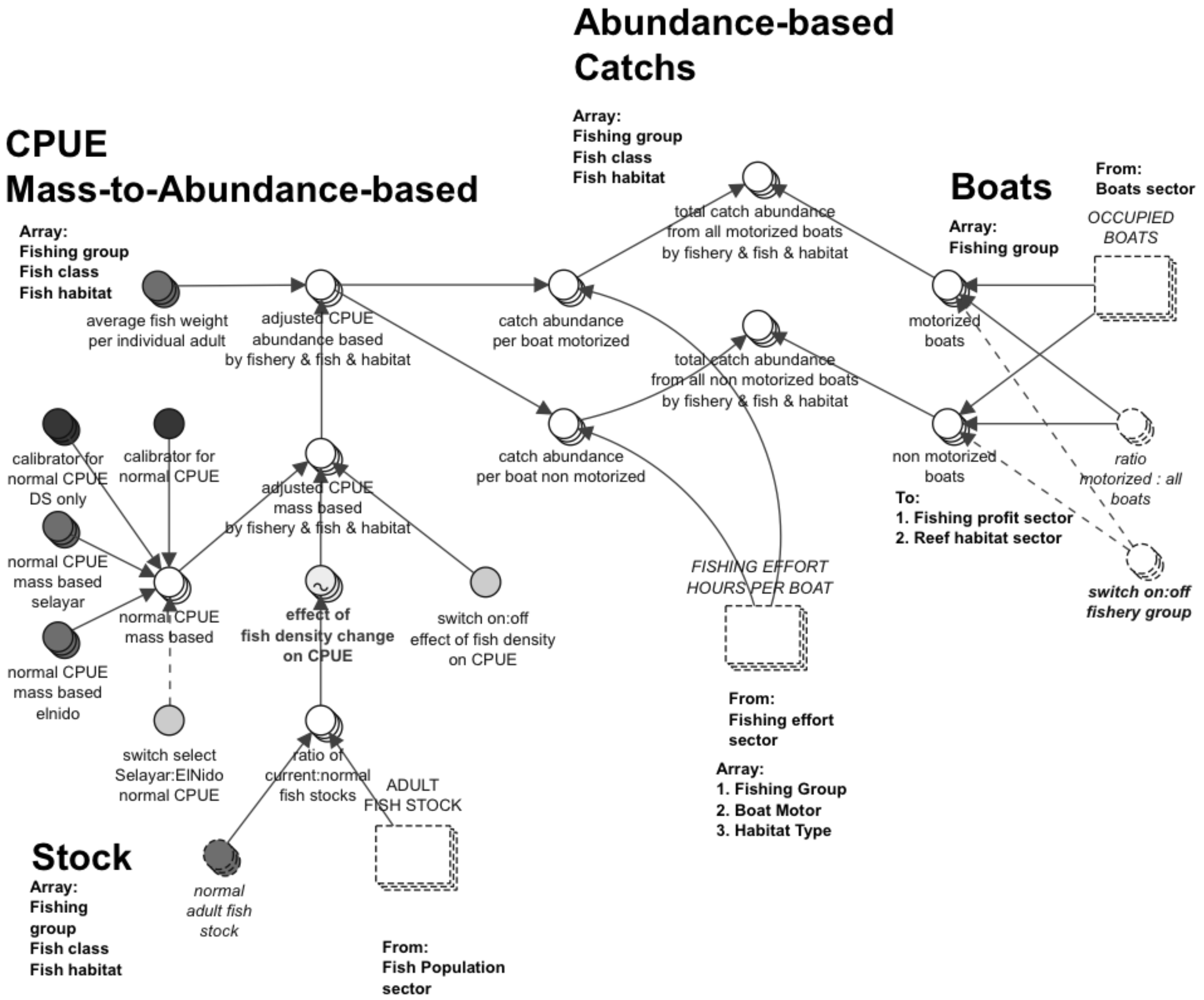
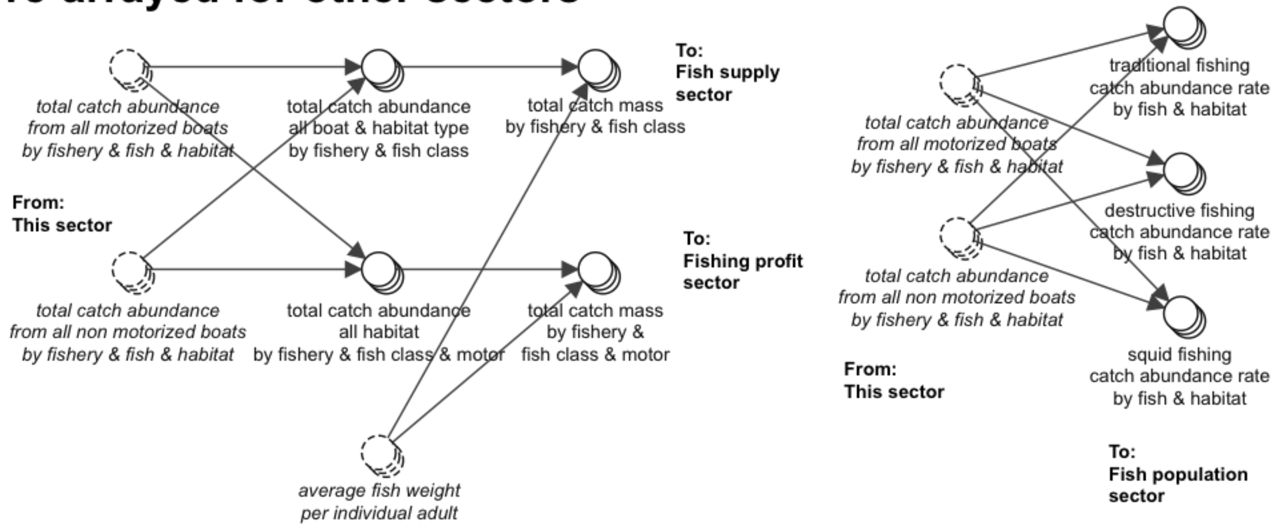


Figure 1-17. Segment 5-A

Fish cath variables re-arrayed for other sectors



Re-array: Sums of catchs

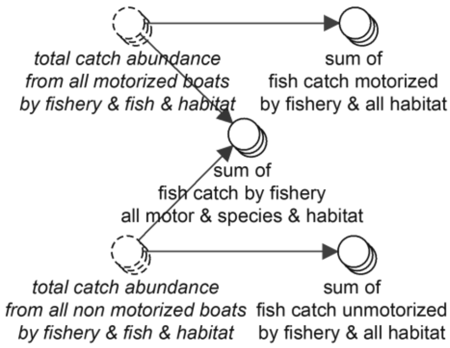


Figure 1-18. Segment 5-B

Sector 6: Fish supply

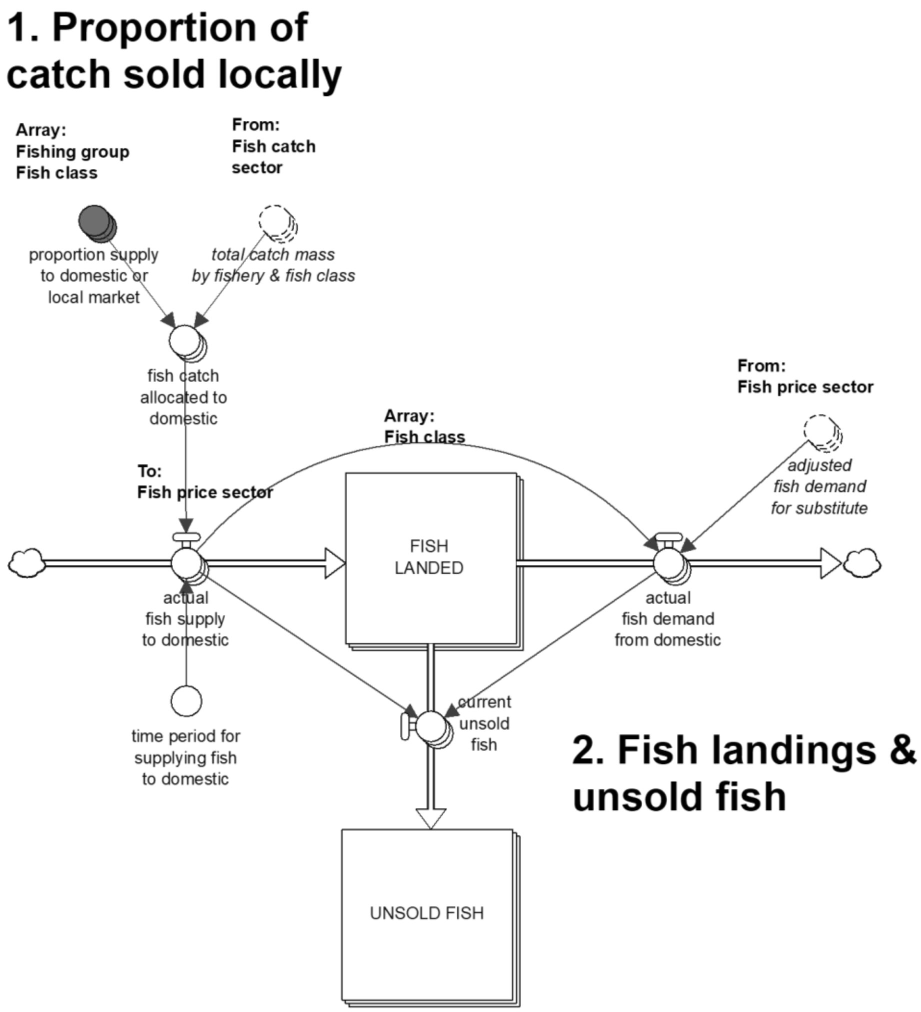


Figure 1-19. SFD of Sector 6

Sector 7: Fish demand and fish price

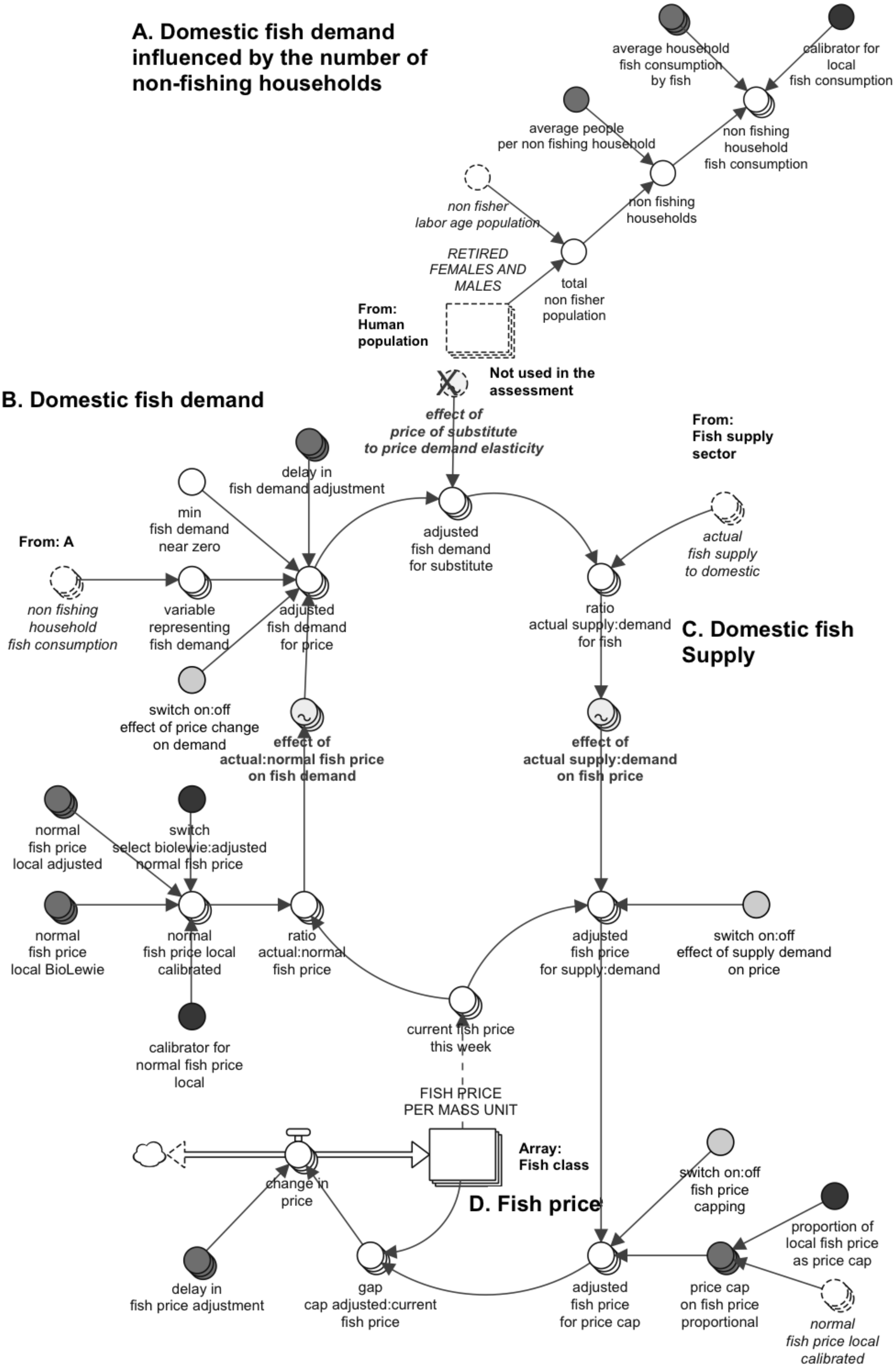


Figure 1-20. SFD of Sector 7

Sector 8: Profit of fishing

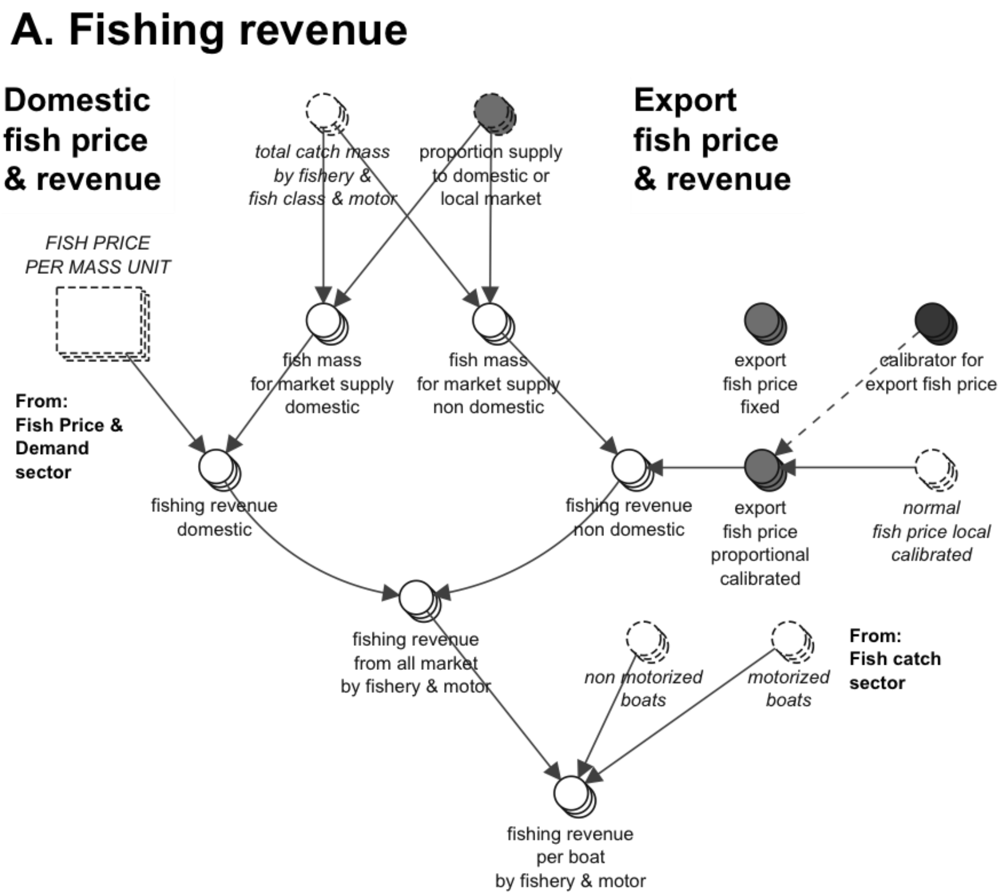


Figure 1-21. Segment 8-A

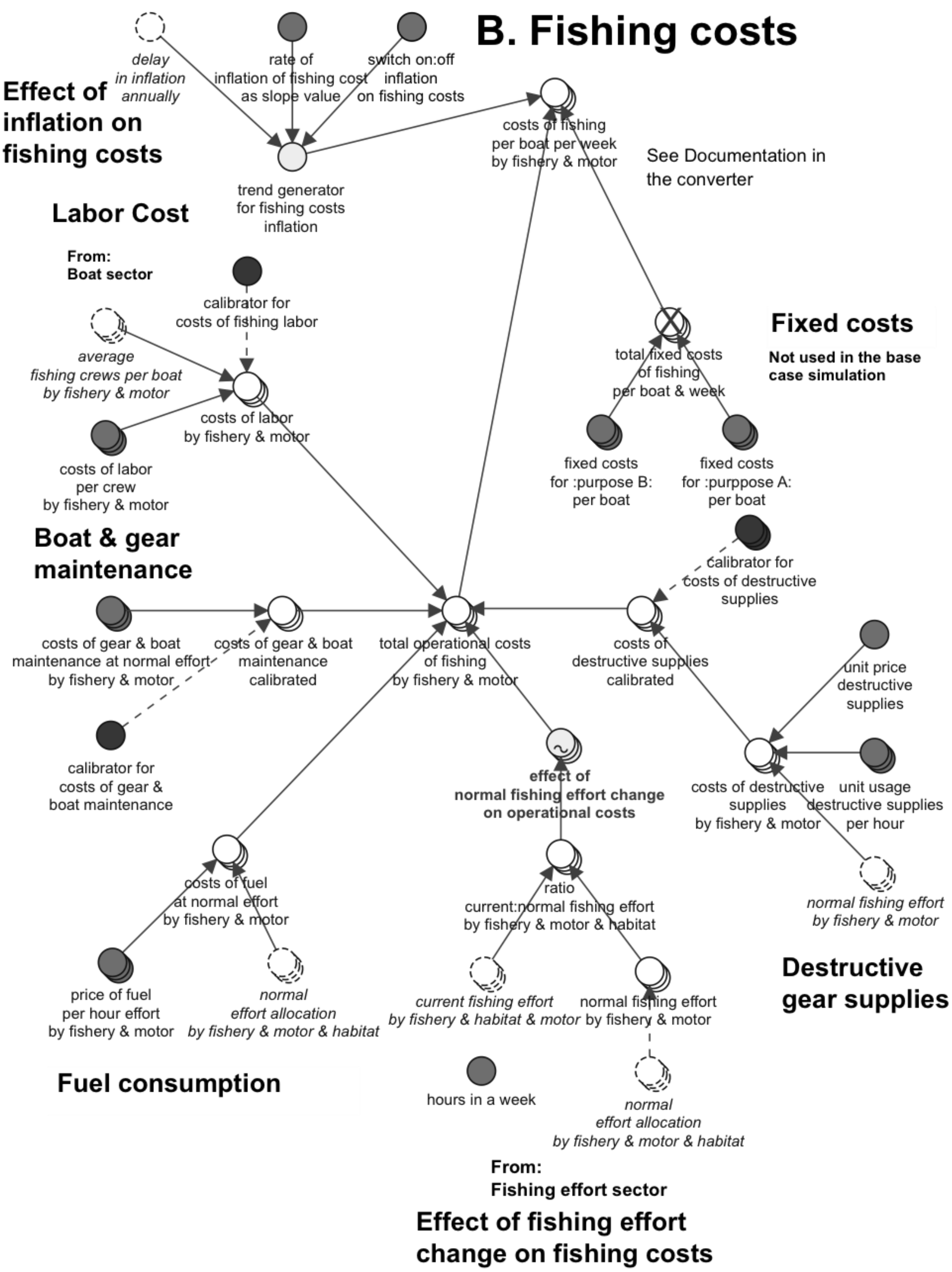


Figure 1-22. Segment 8-B

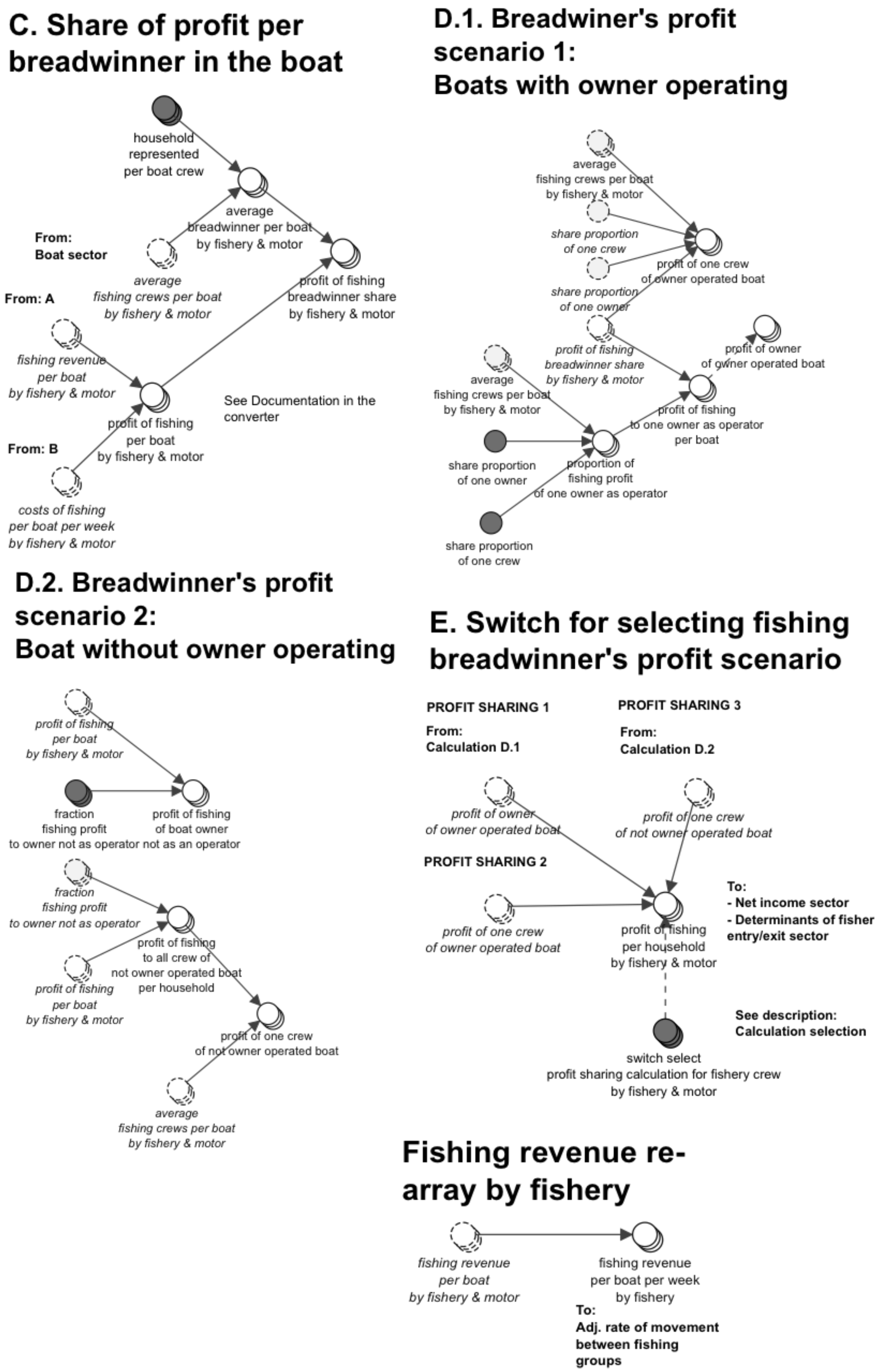


Figure 1-23. Segment 8-C, D, and E

Sector 9: Effort for fishing

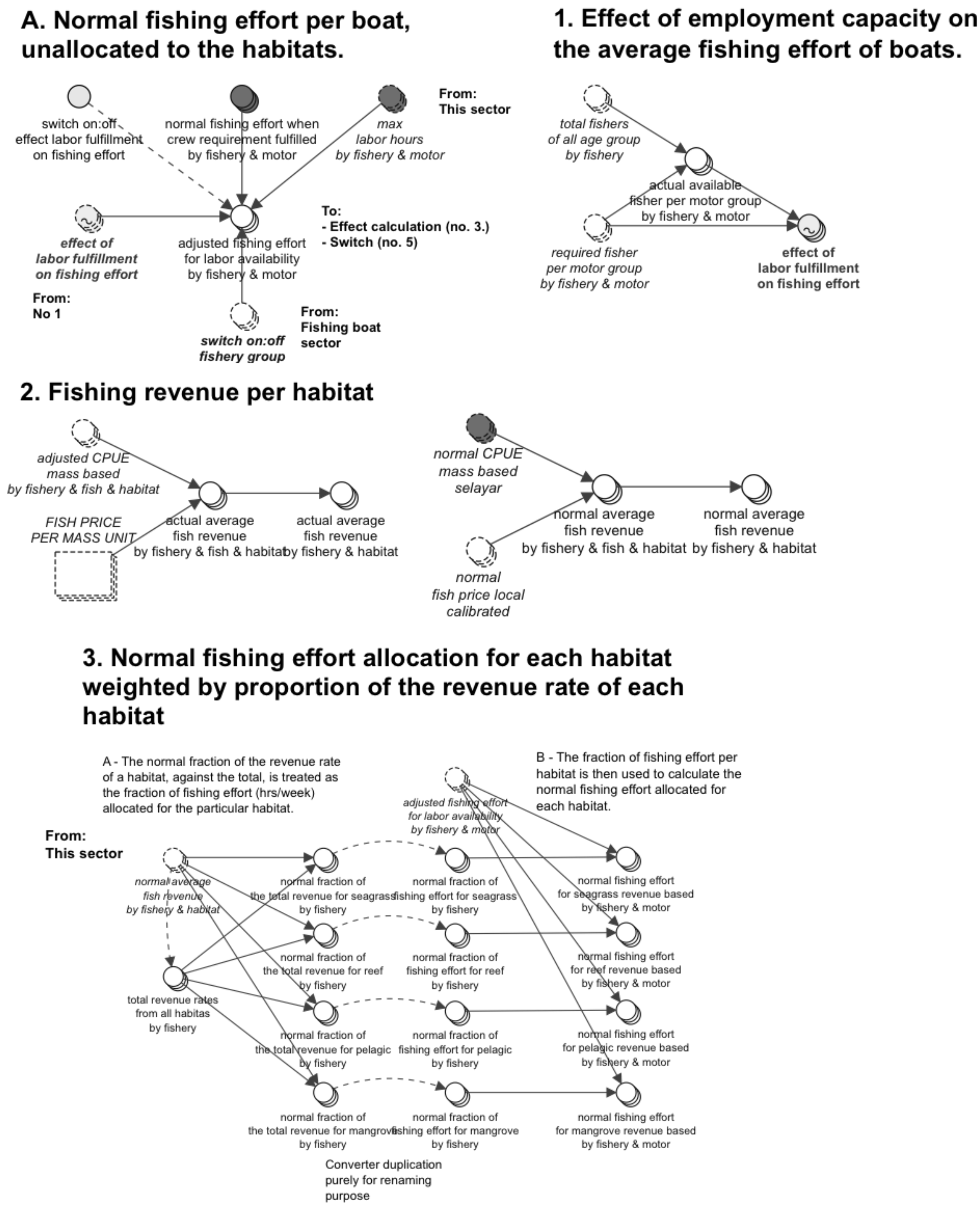


Figure 1-24. Segment 9-A

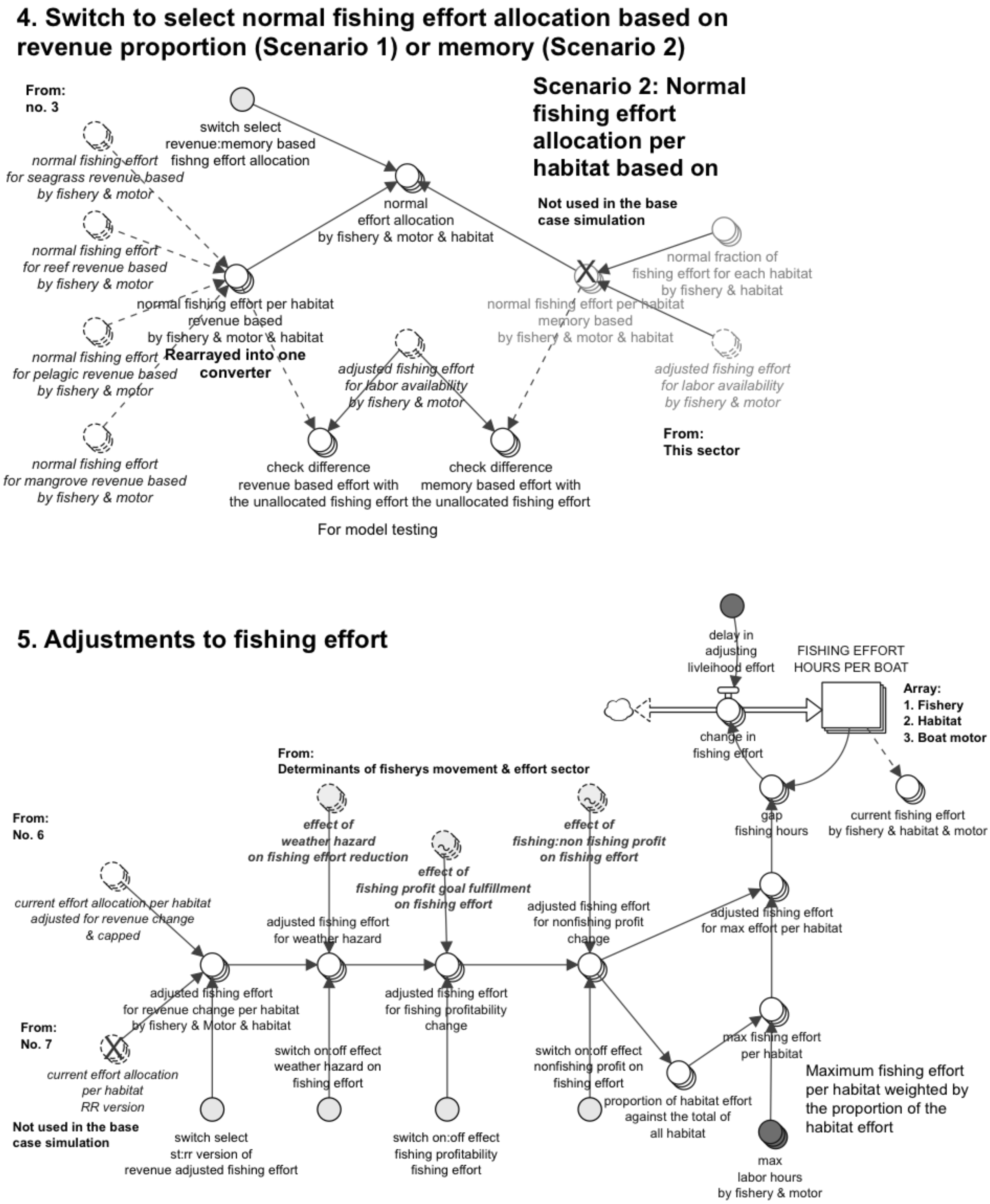


Figure 1-25. Segment 9-B

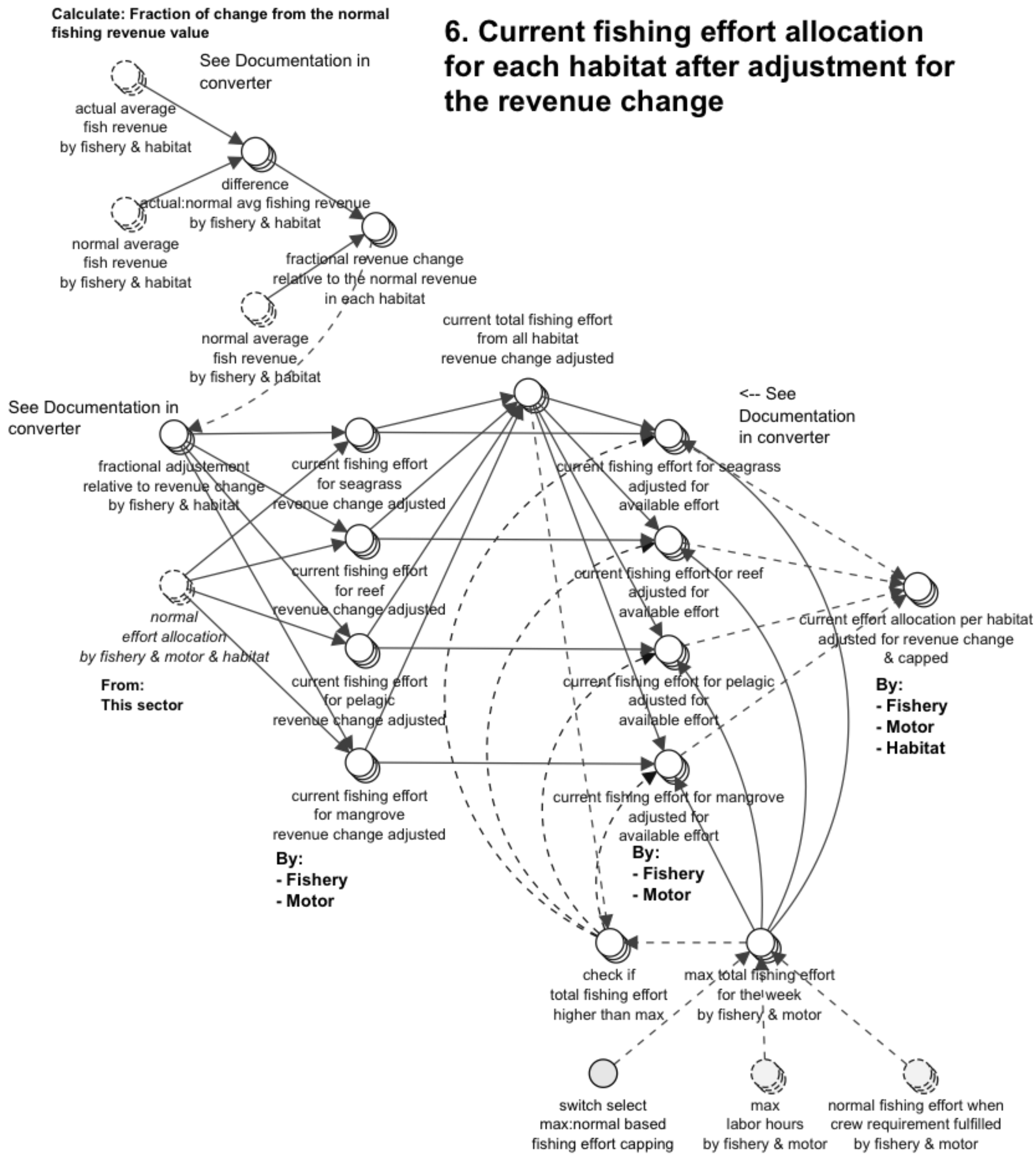


Figure 1-26. Segment 9-C

Sector 10: Effort for non-fishing (by fishers)

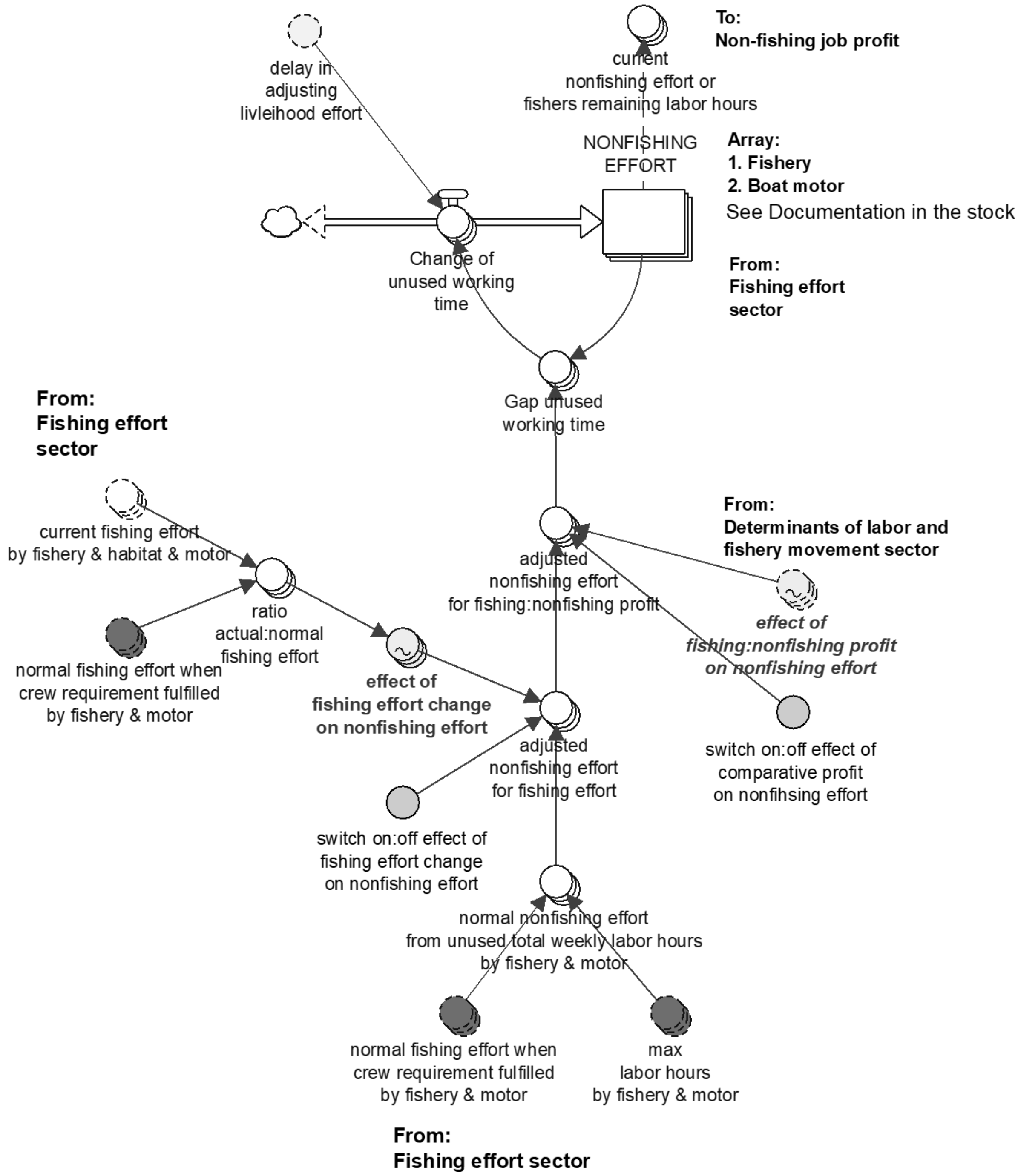


Figure 1-27. SFD of Sector 10

Sector 11: Effort for non-fishing work (by non-fishers)

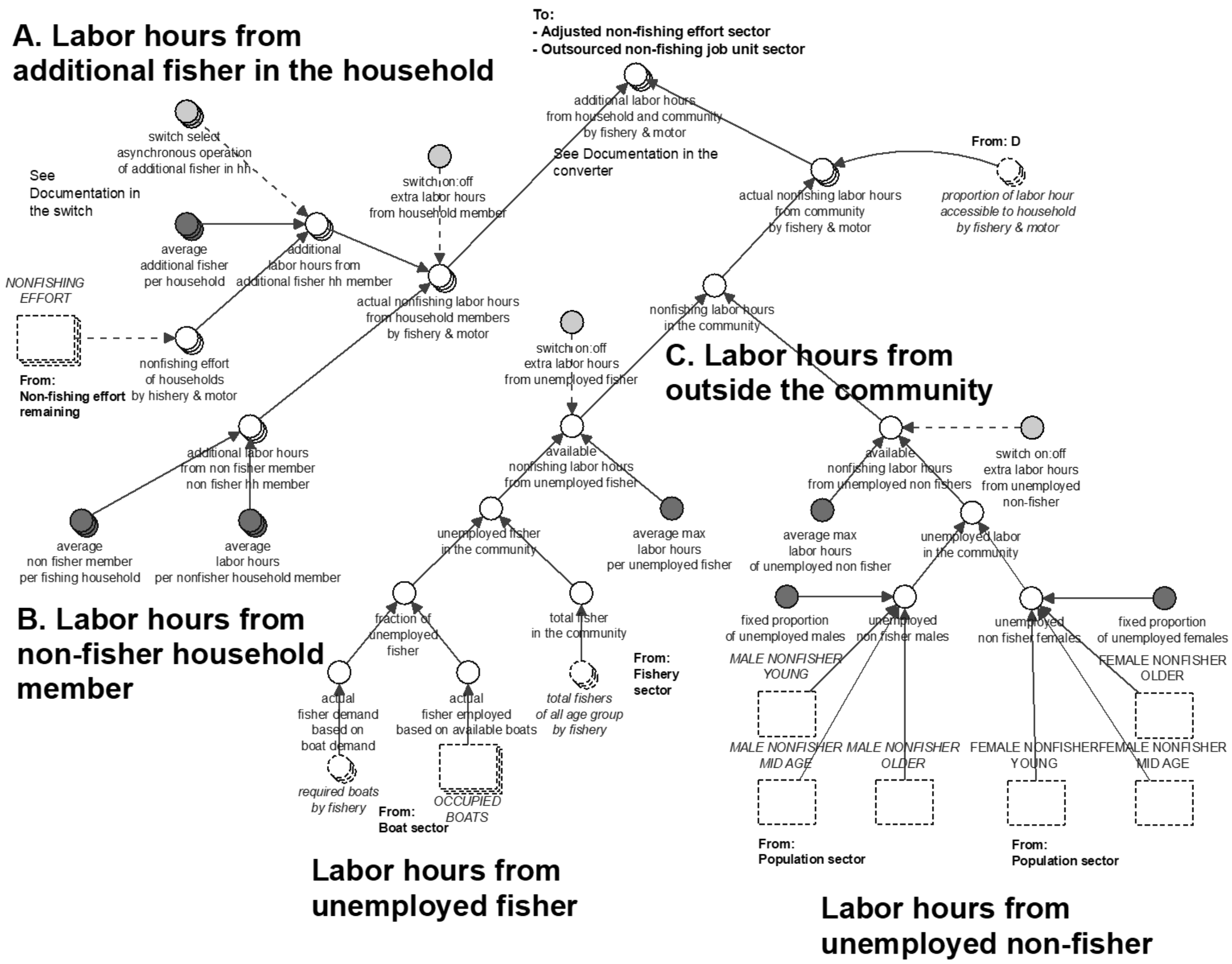


Figure 1-28. Segment 11-A

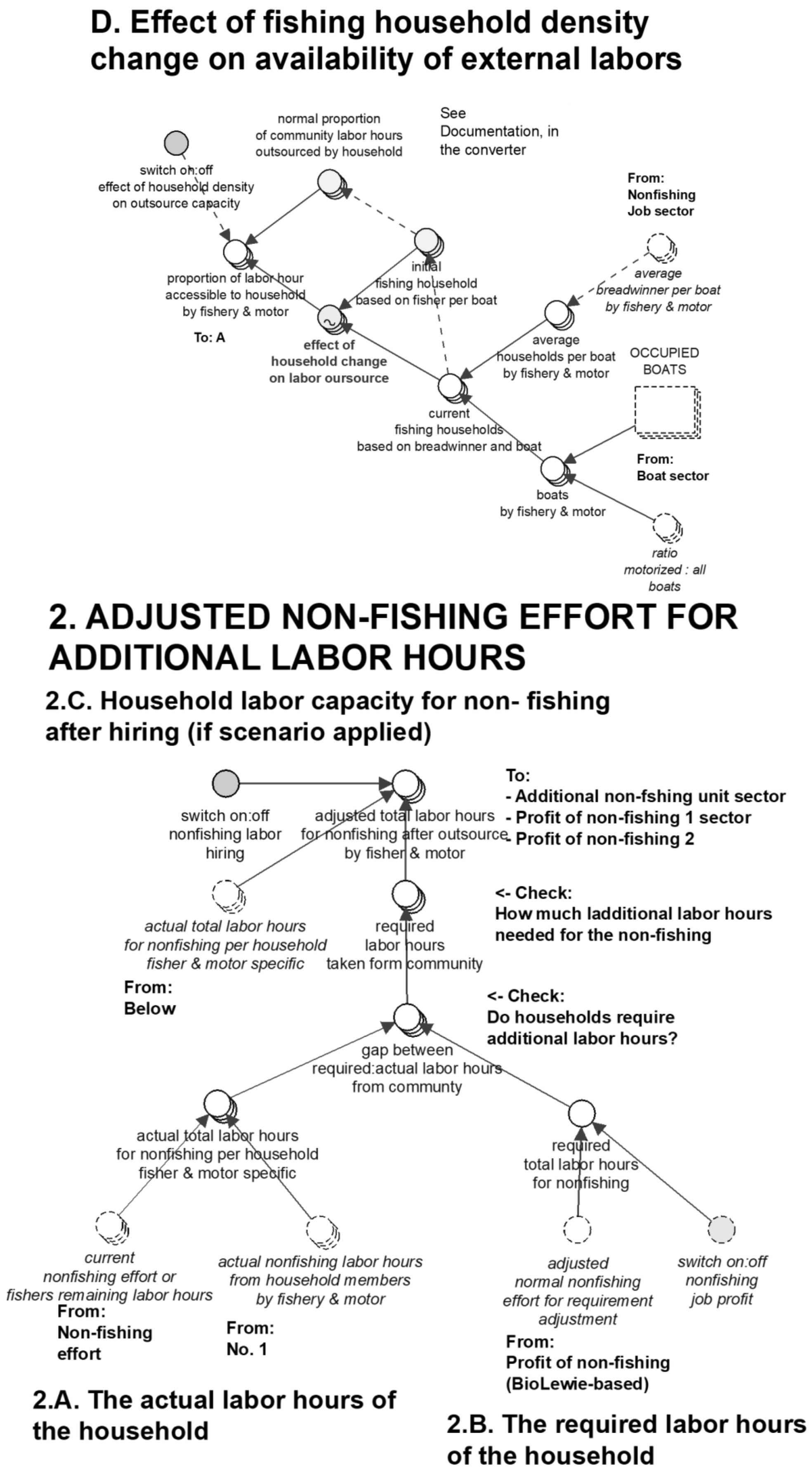


Figure 1-29. Segment 11-B

Sector 12: Household costs of living

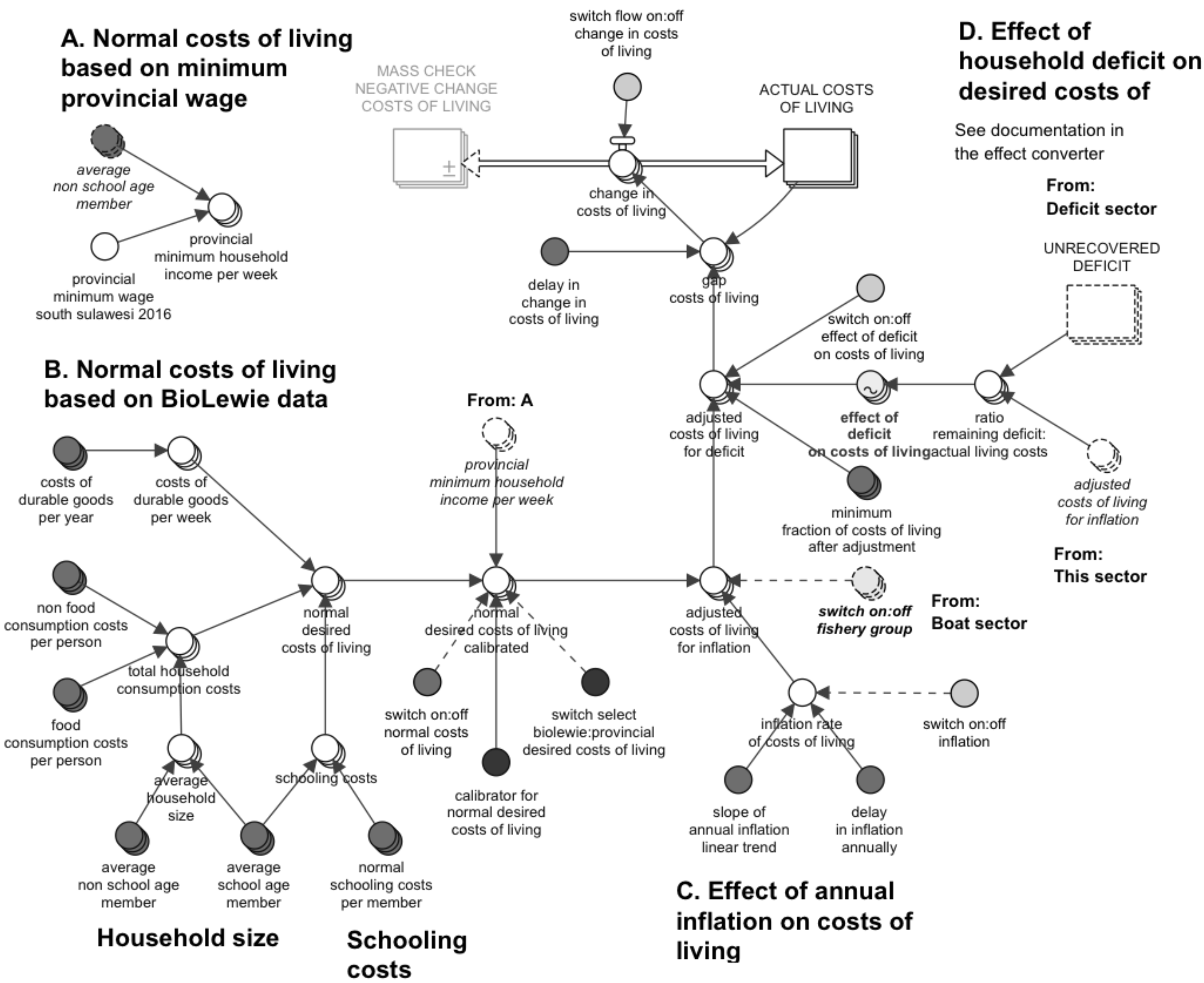


Figure 1-30. SFD of Sector 12

Sector 13: Household net income (savings)

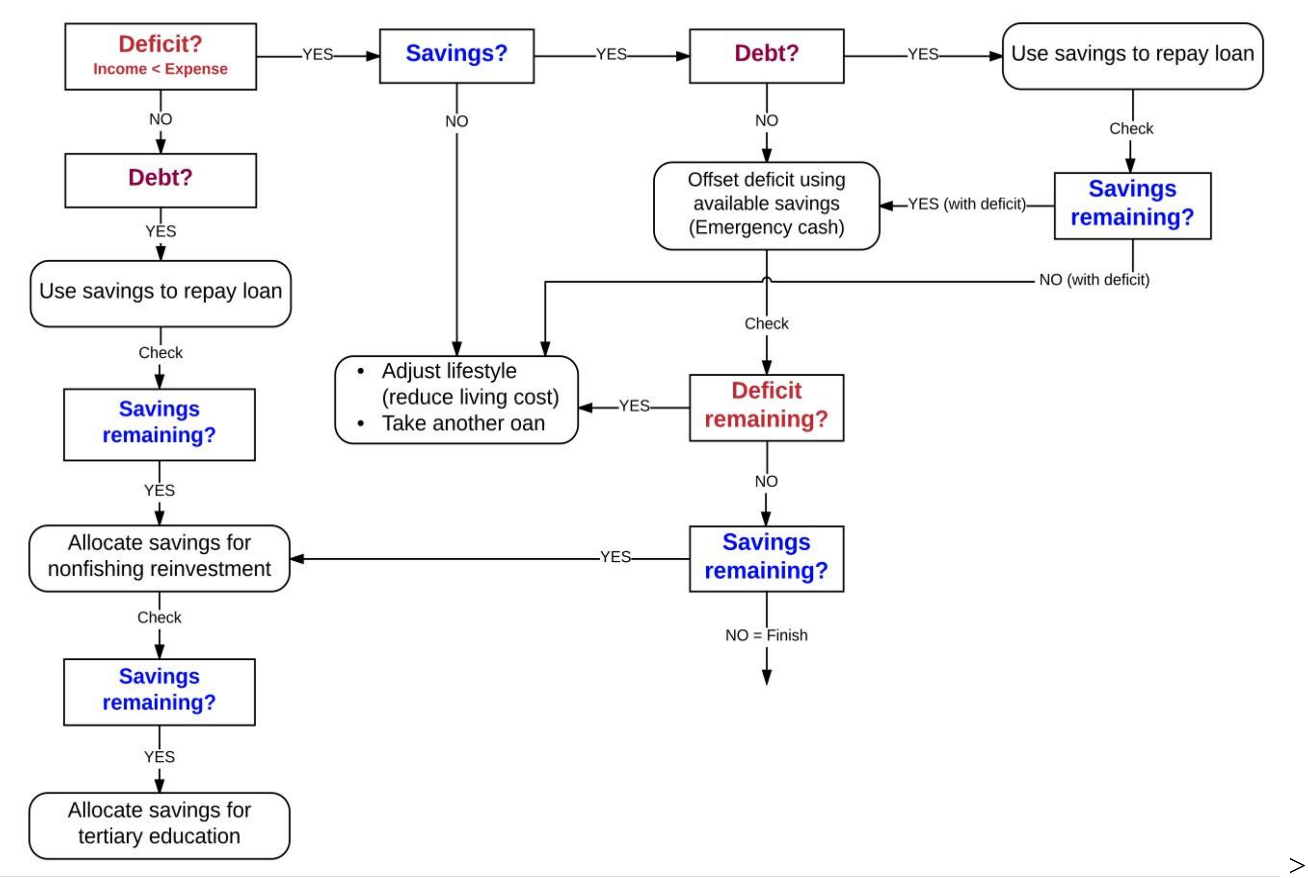


Figure 1-31. Decision flowchart

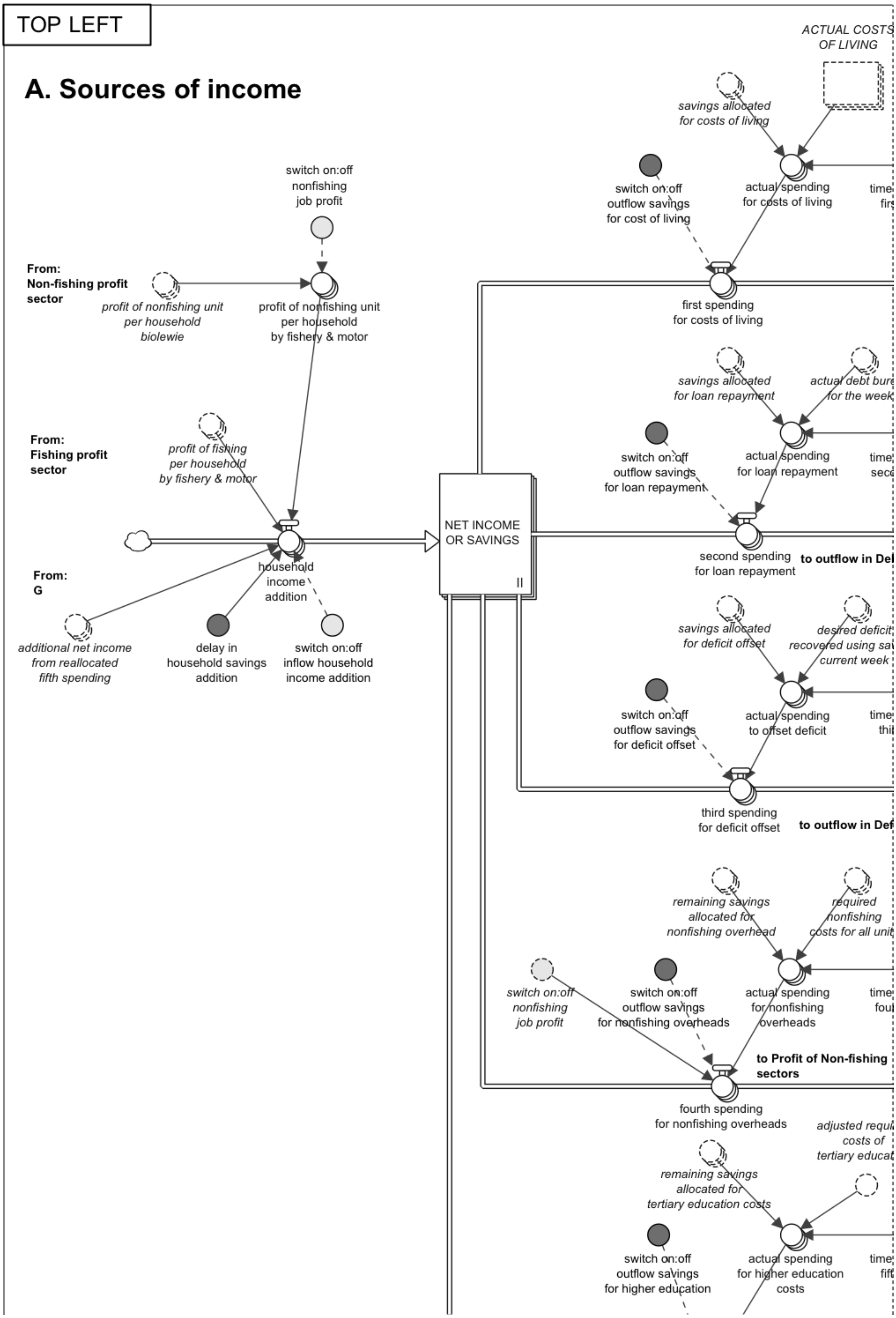


Figure 1-32. Top left

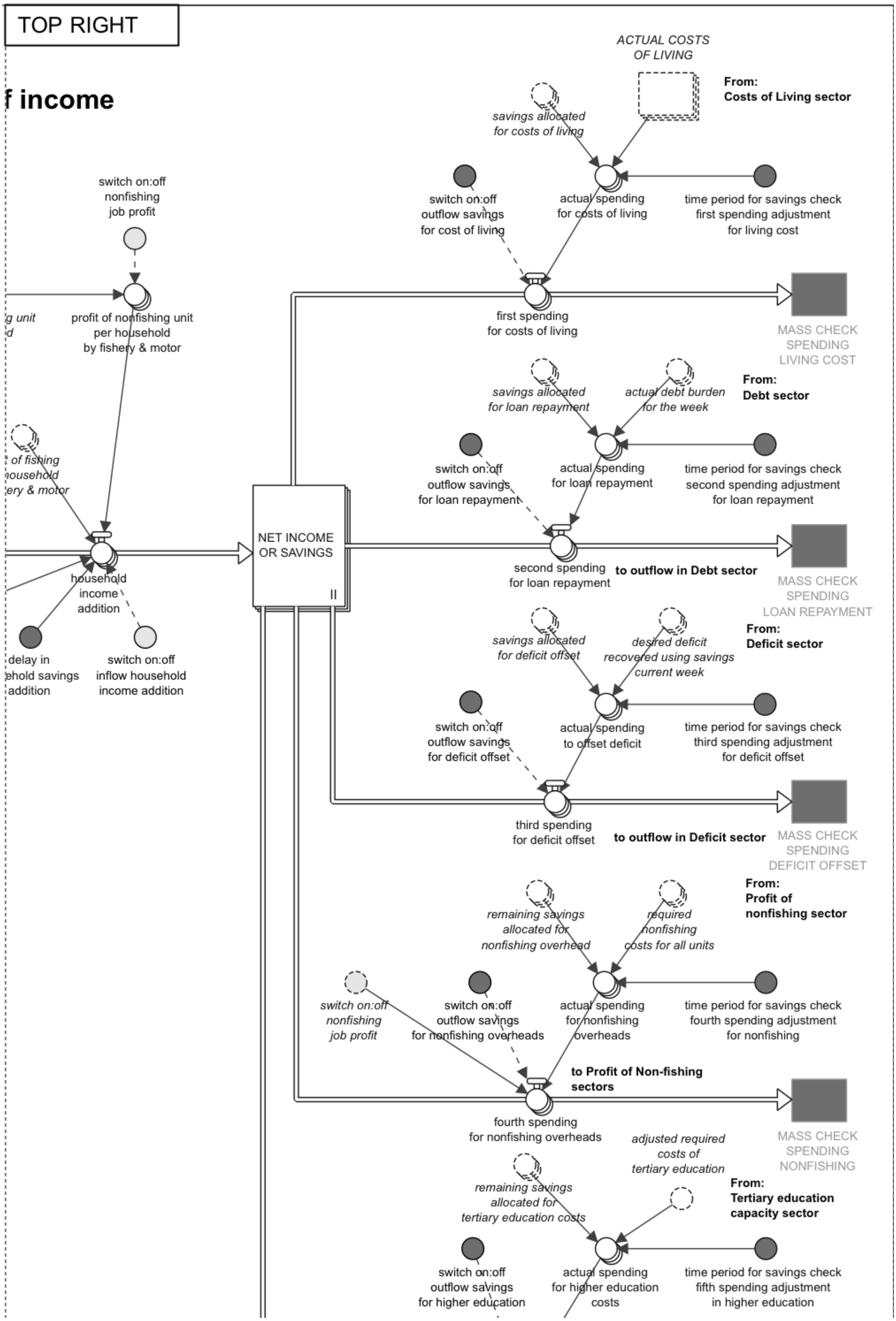


Figure 1-33. Top right

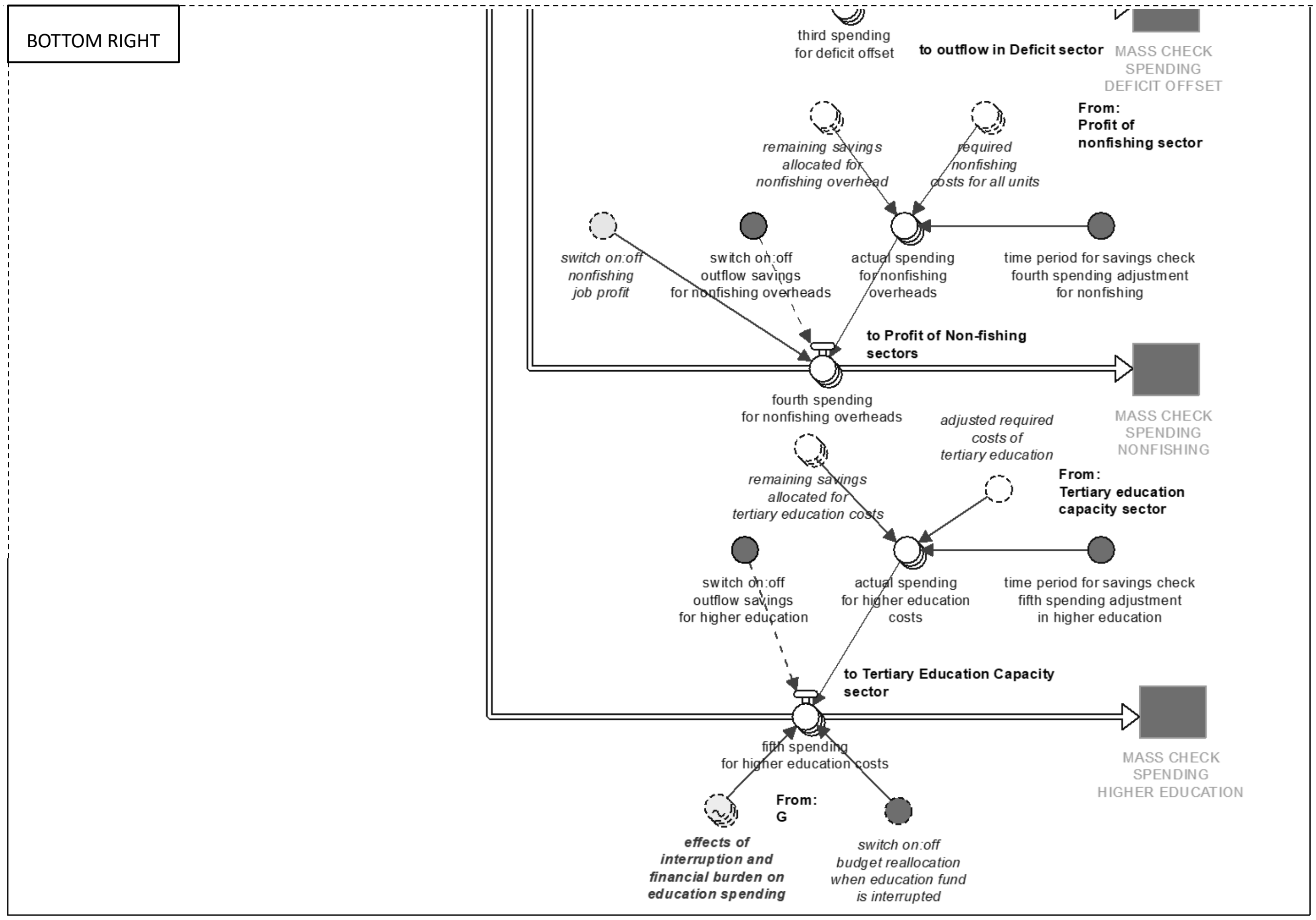


Figure 1-34. Bottom right and

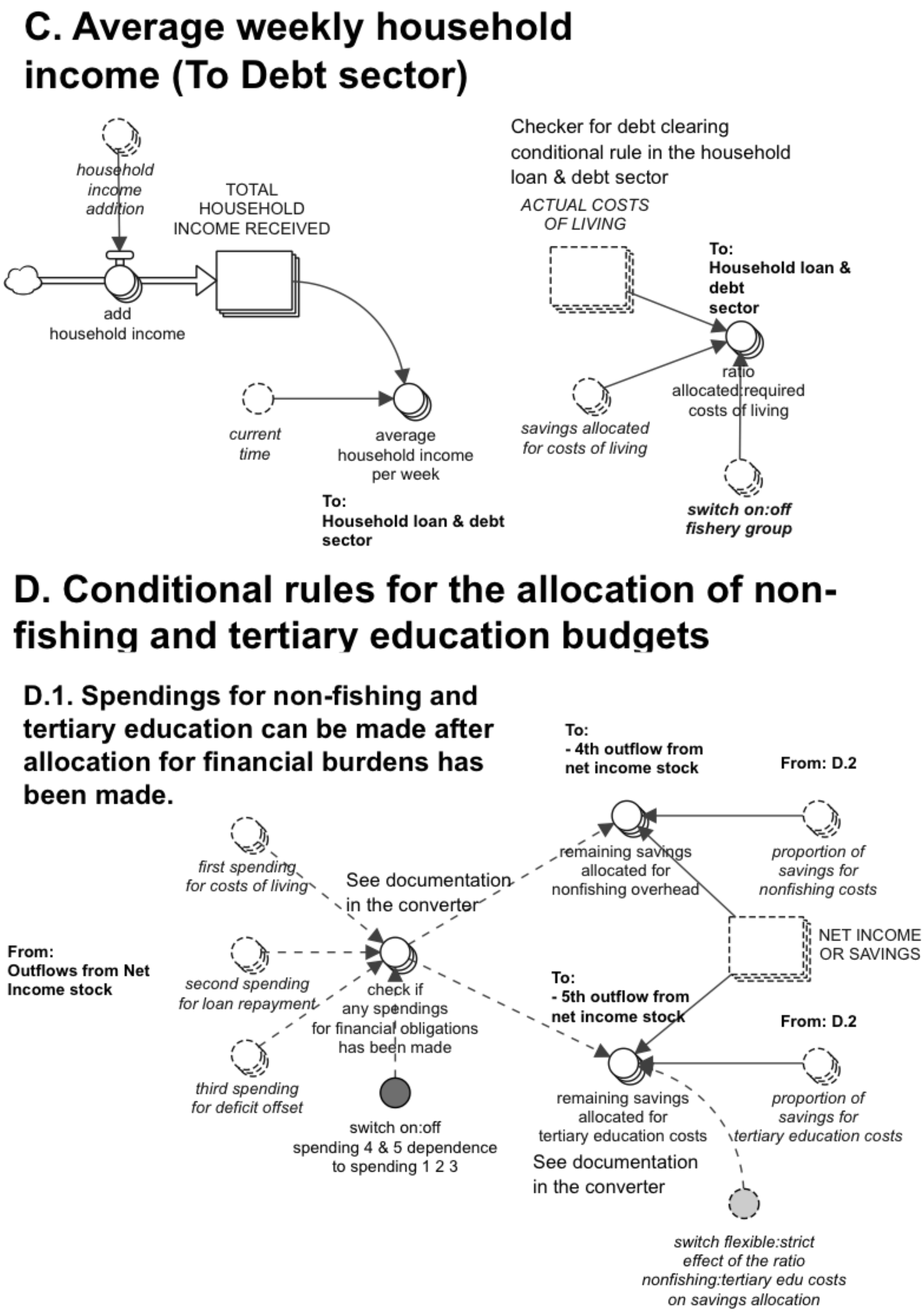
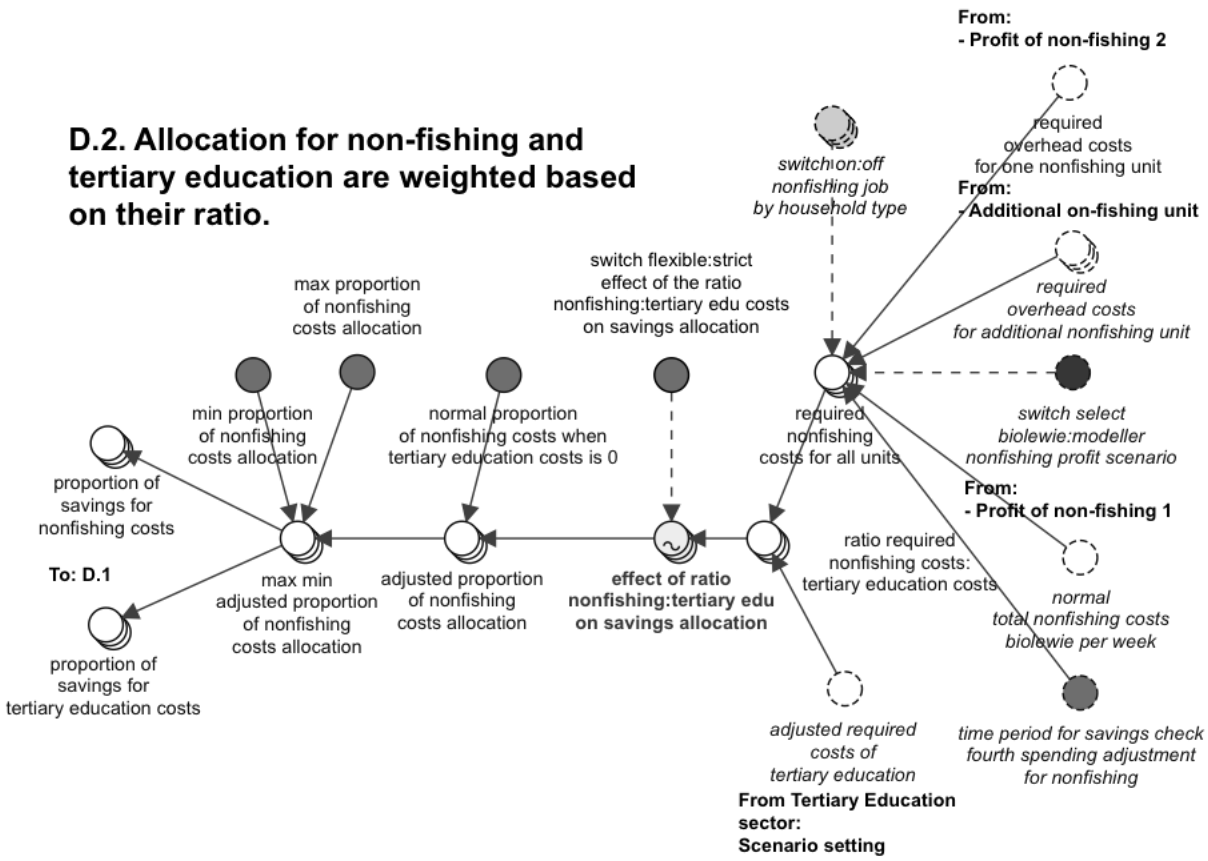


Figure 1-35. Segment 13-A

D.2. Allocation for non-fishing and tertiary education are weighted based on their ratio.



E. Prioritization of saving allocation weighted by the proportion of the financial burdens/obligaitons

E.1. Two financial burdens weighting

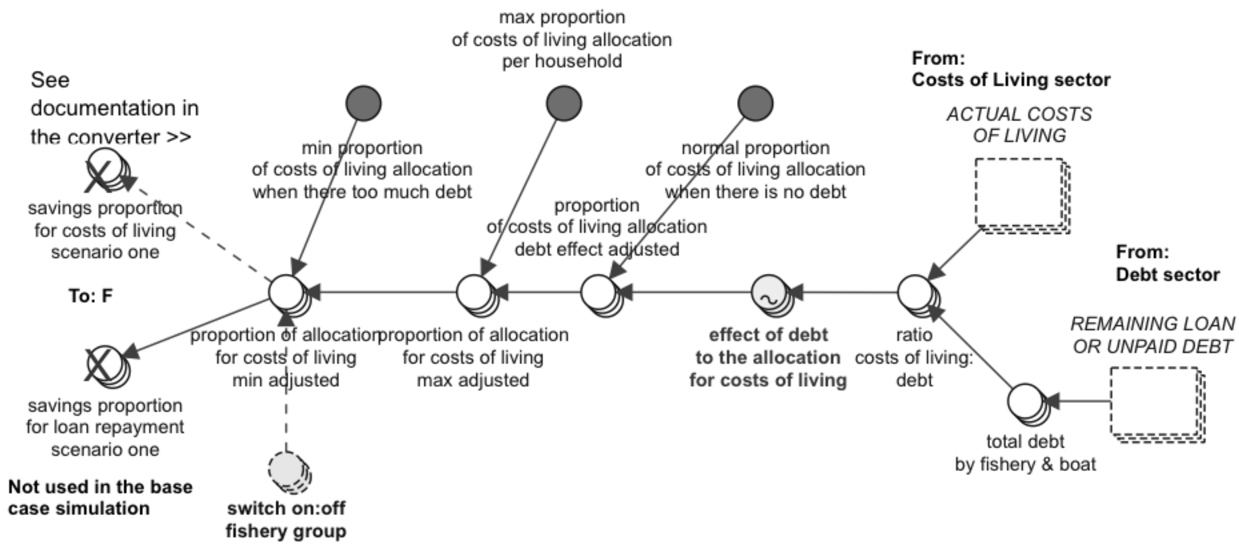
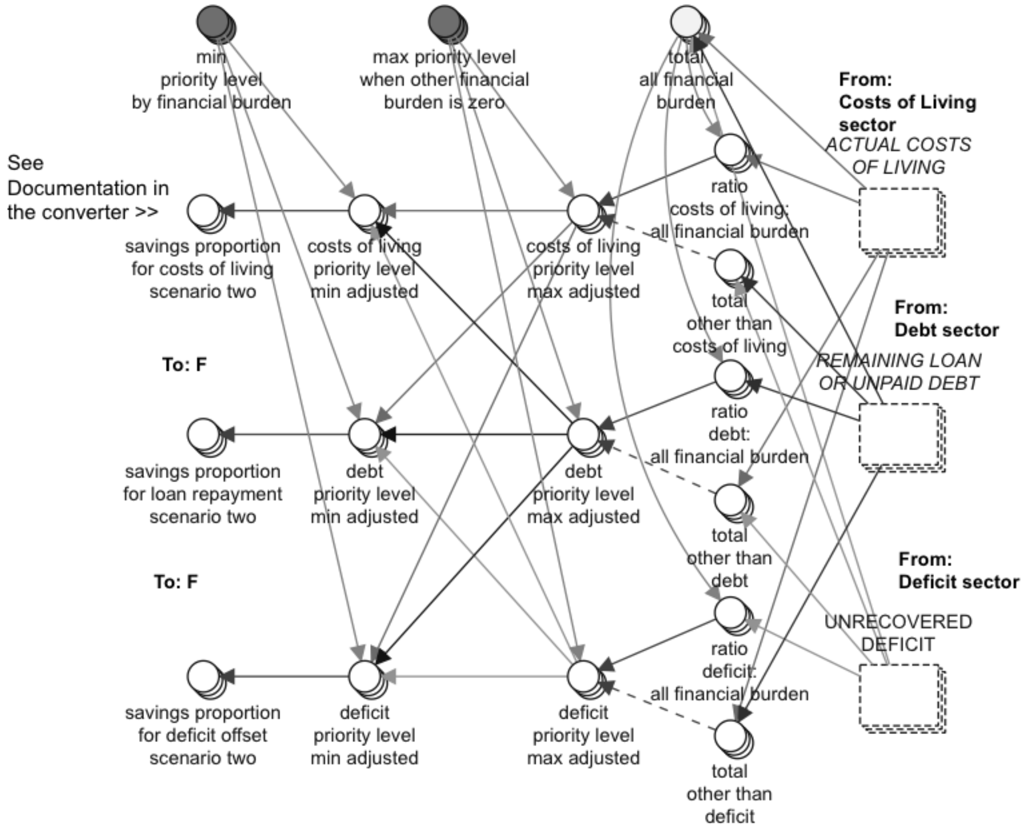


Figure 1-36. Segment 13-B

E.2. Three financial burdens weighting



F. Switch for selecting spending allocation prioritization approach

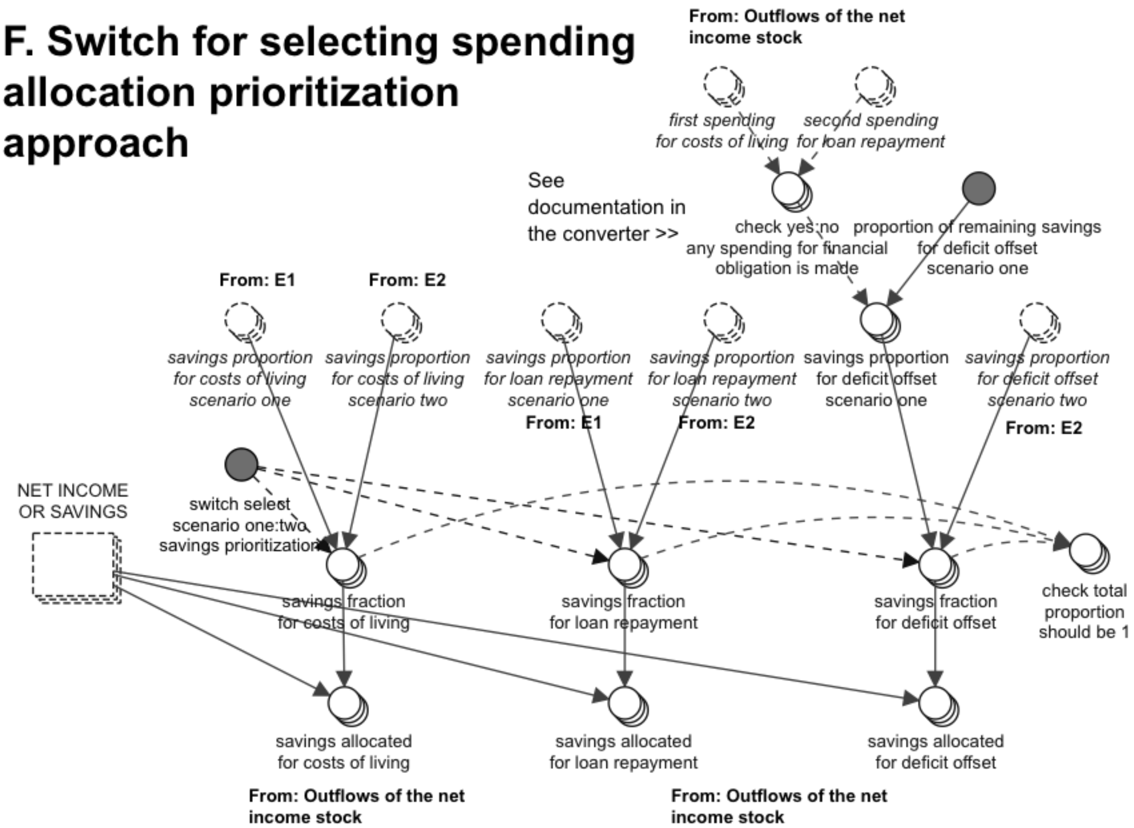
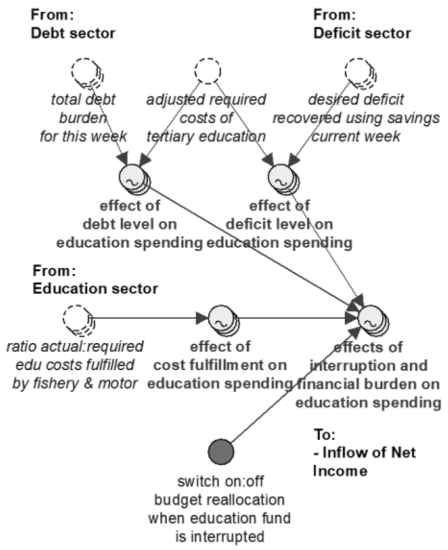


Figure 1-37. Segment 13-C

G.1. Effect of education financing interruption, debt, and deficit on reallocation of education spending



G.2. Current education spending reallocated to financial burden

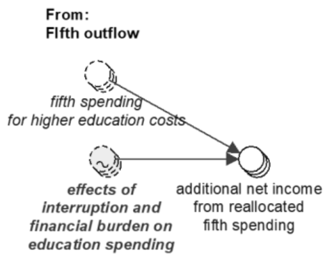


Figure 1-38. Segment 14-D

Sector 14: Household deficit level

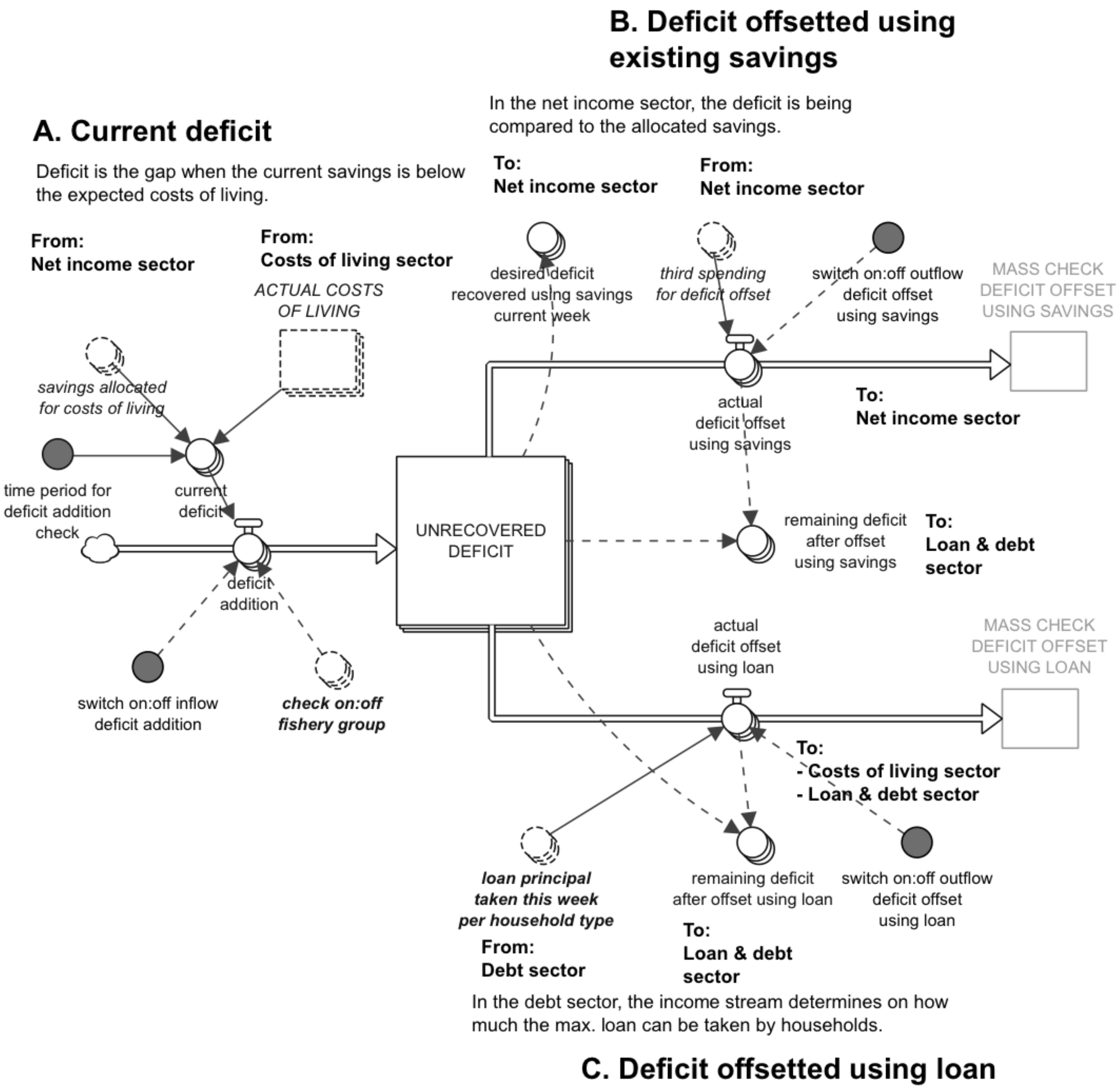


Figure 1-39. SFD of Sector 14

Sector 15: Household tertiary education capacity

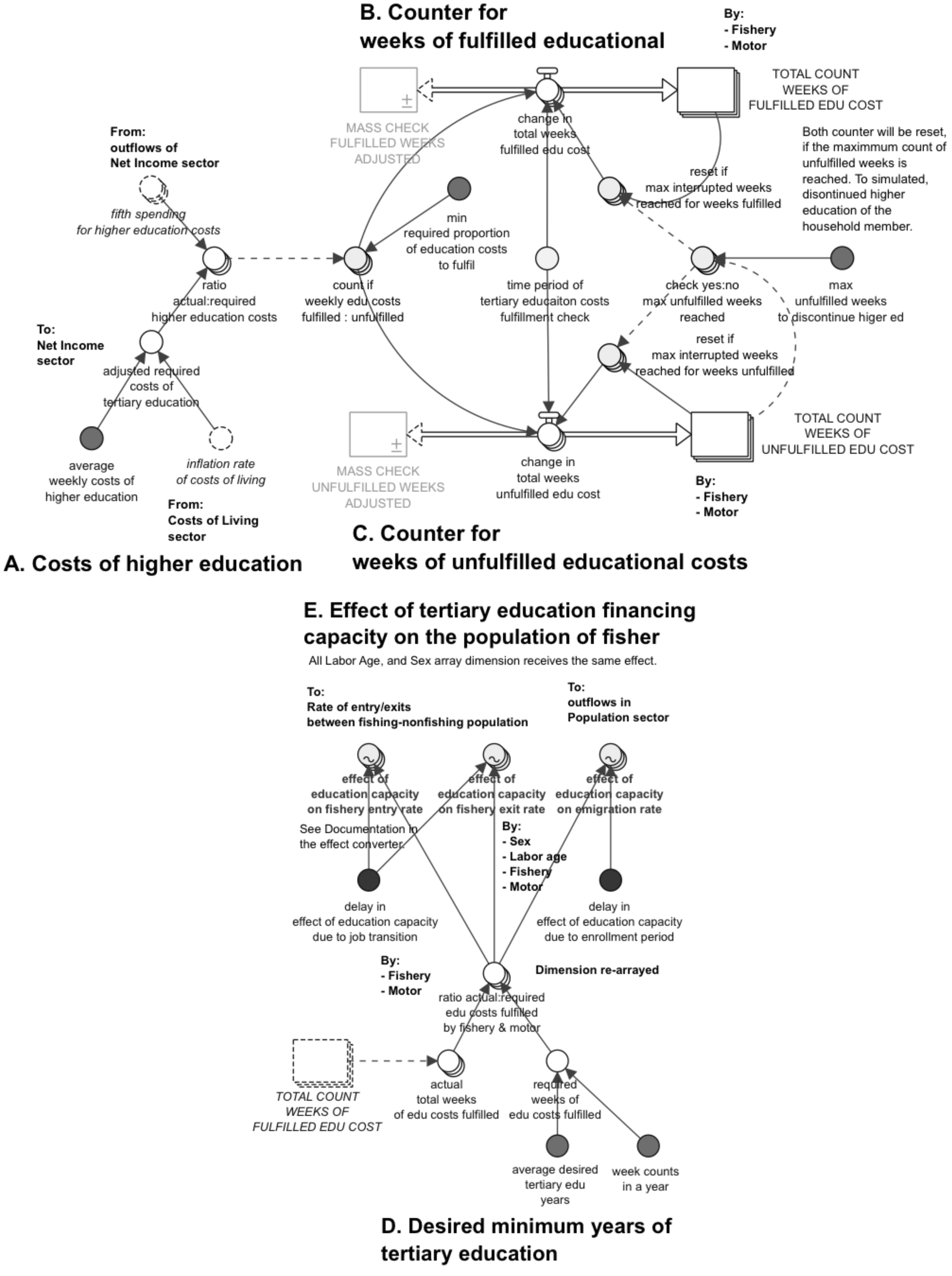


Figure 1-40. SFD of Sector 15

Sector 16: Population of human

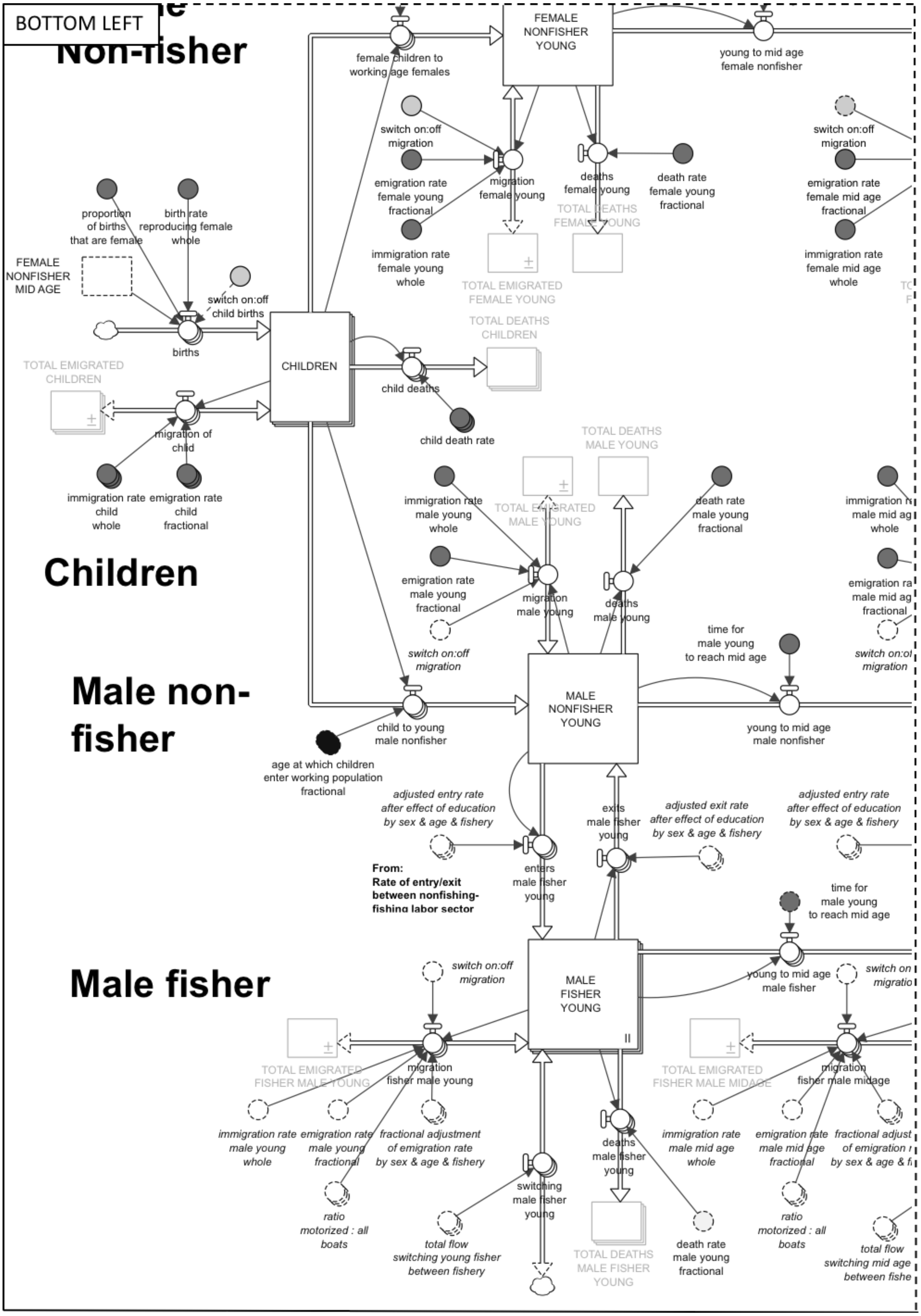


Figure 1-41. Bottom left

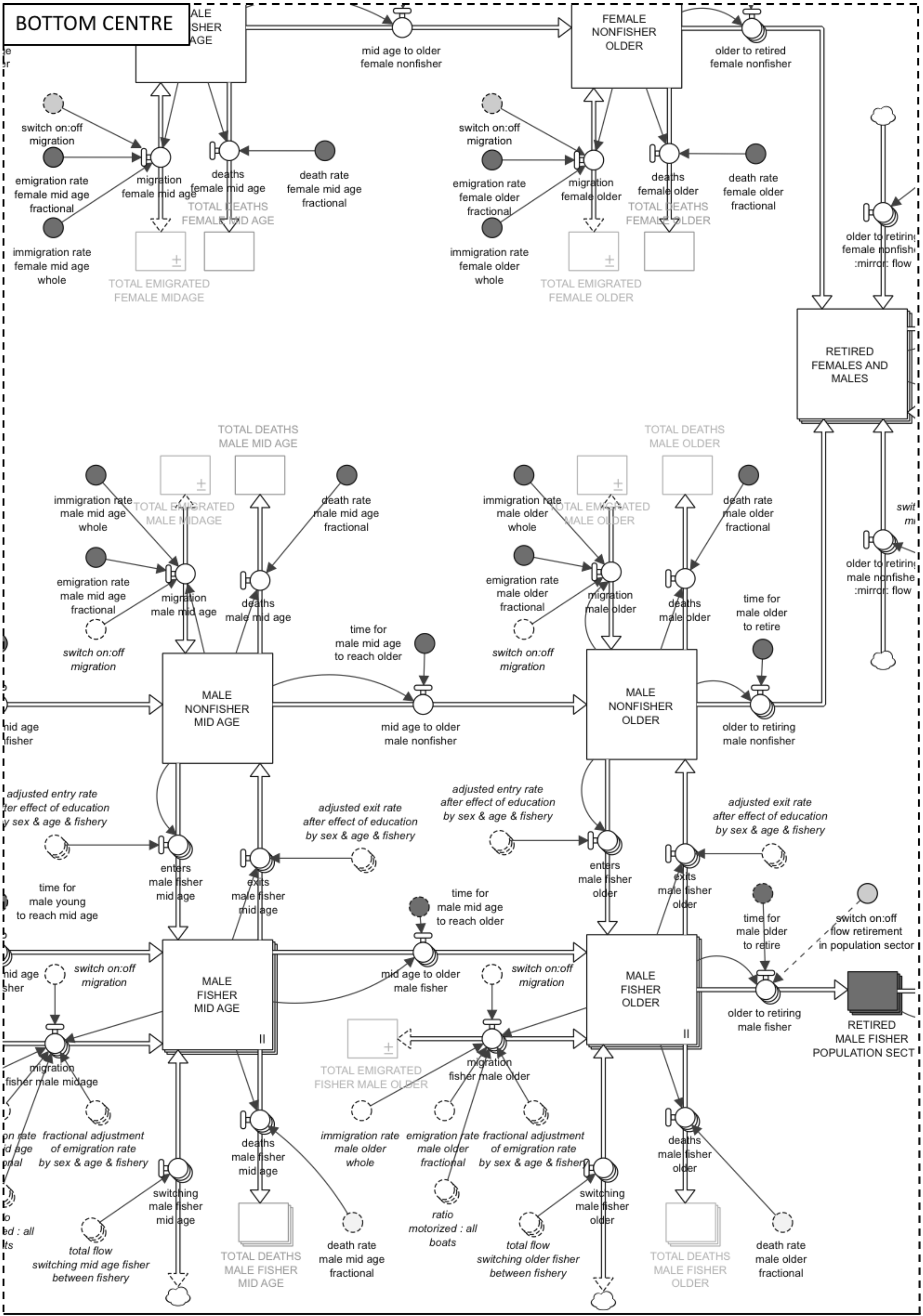


Figure 1-42. Bottom centre

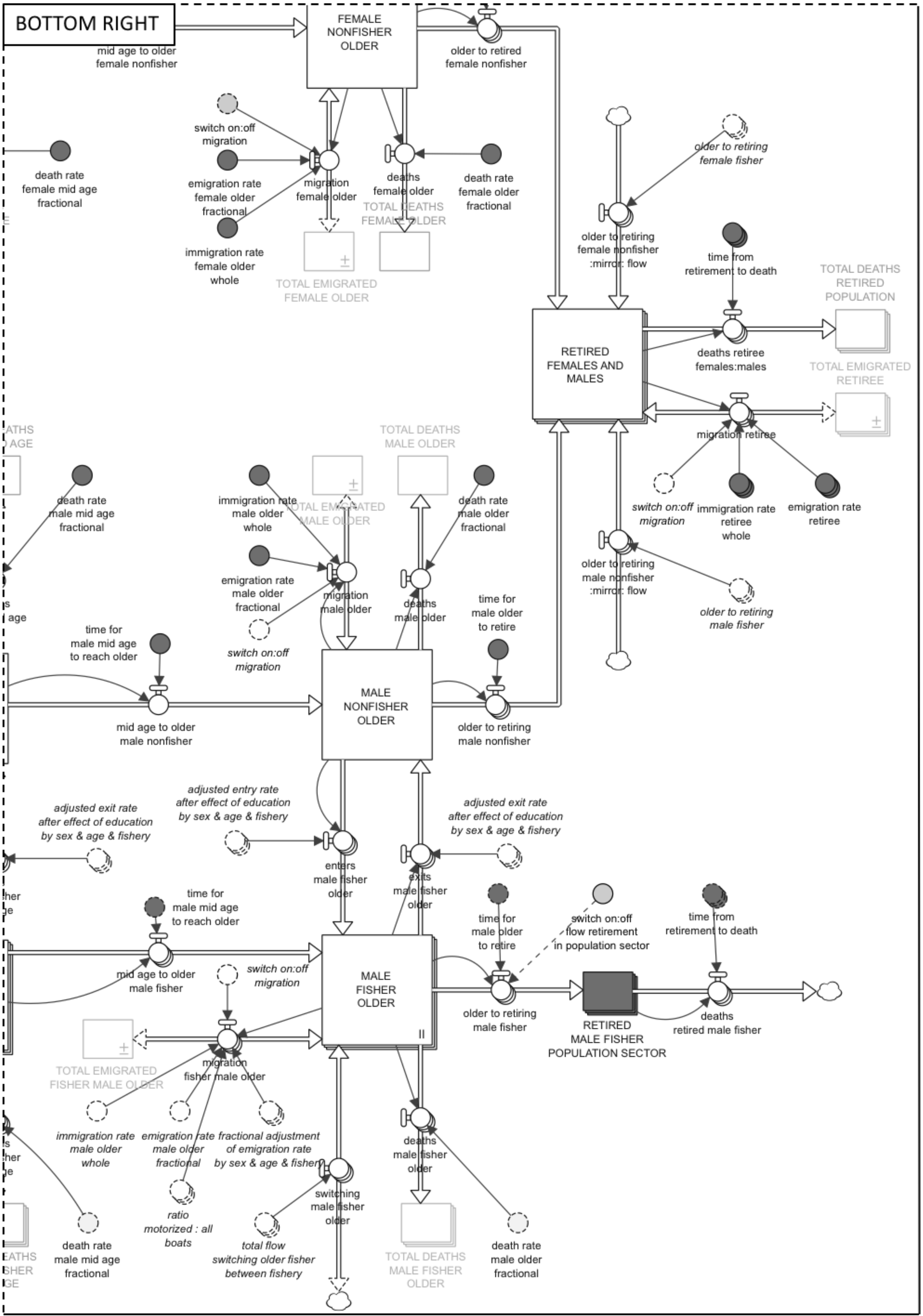


Figure 1-43. Bottom right

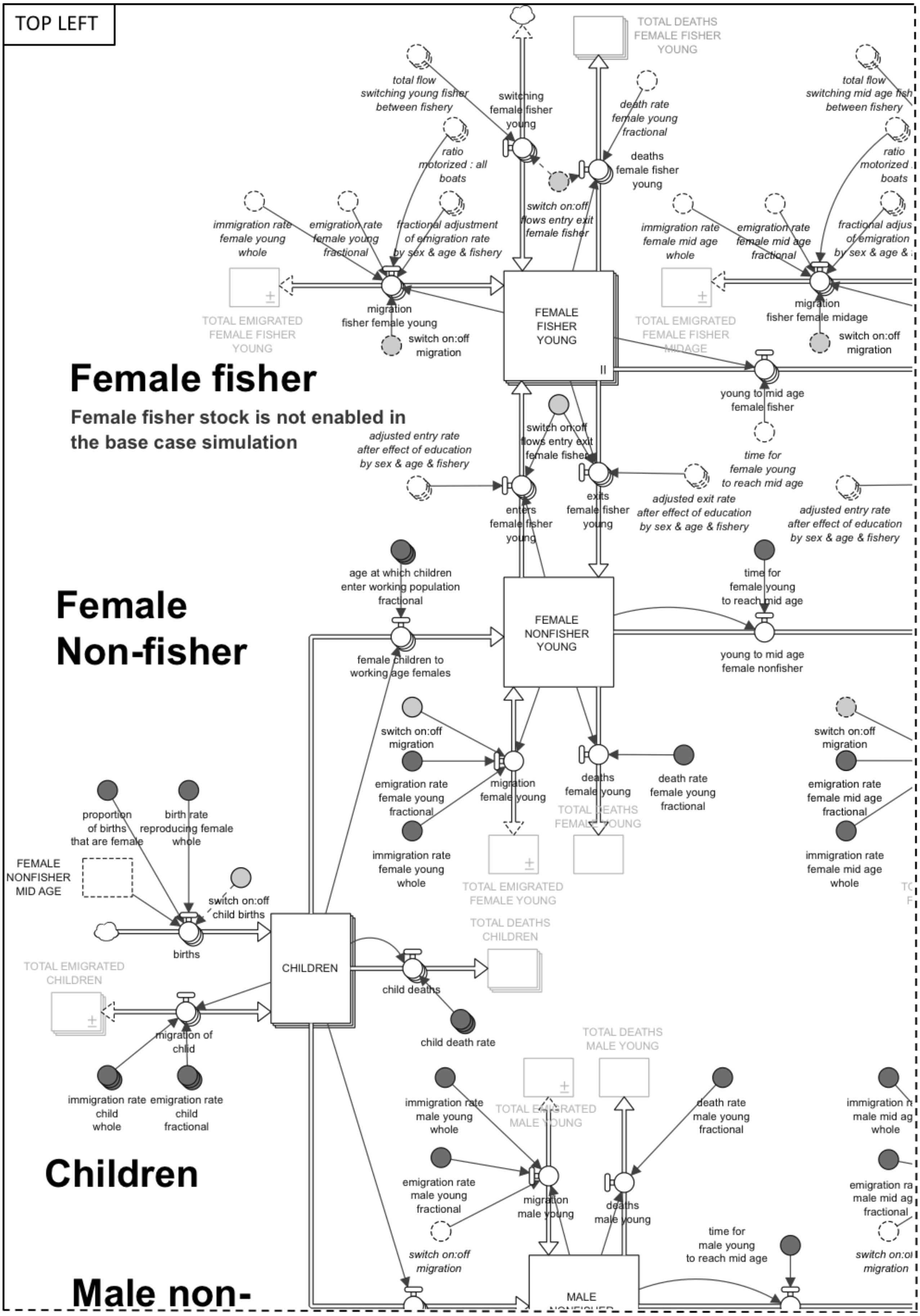


Figure 1-44. Top left

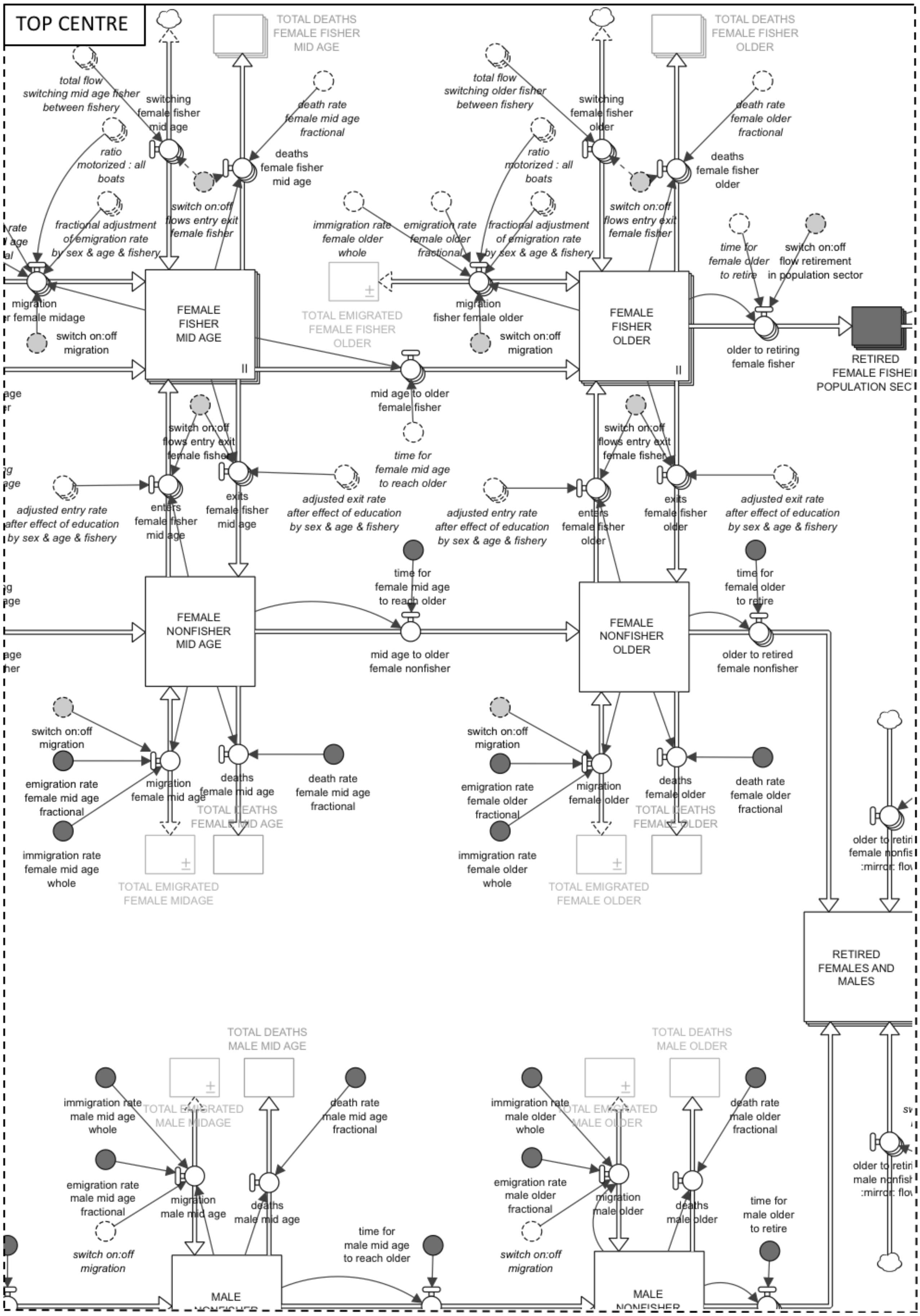


Figure 1-45. Top centre

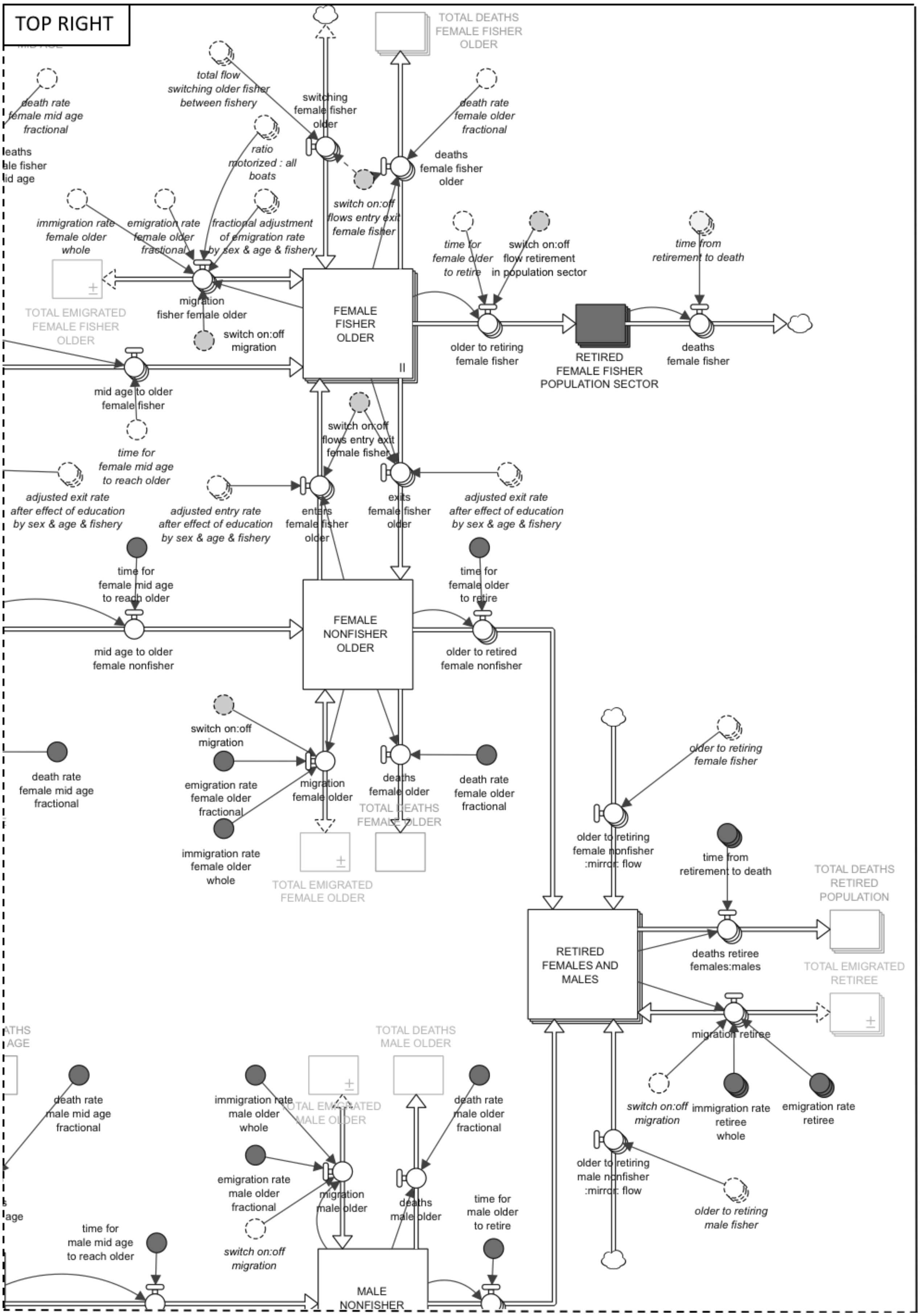


Figure 1-46. Top right

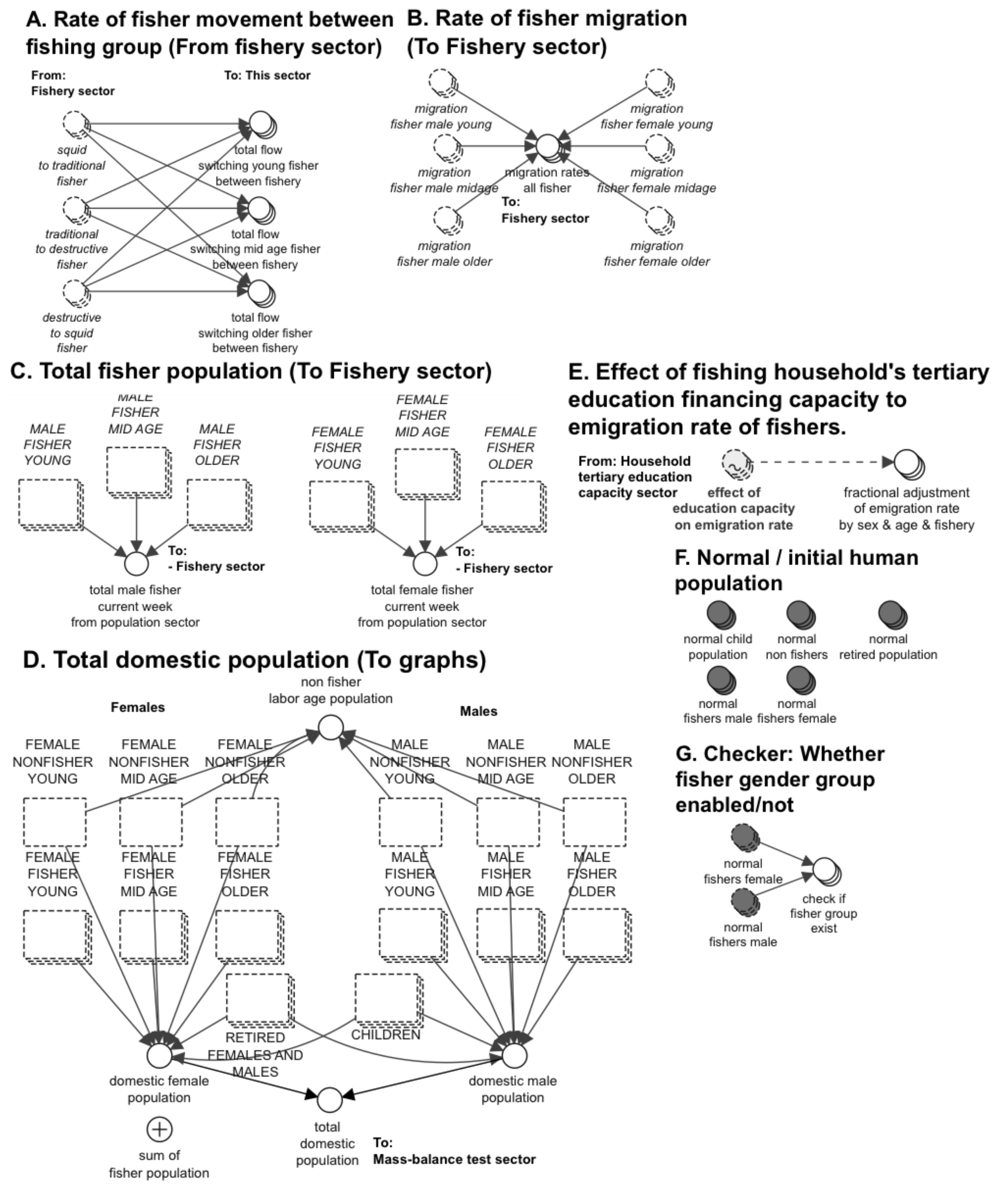


Figure 1-47. Segment 16-A

Sector 17: Fishery groups

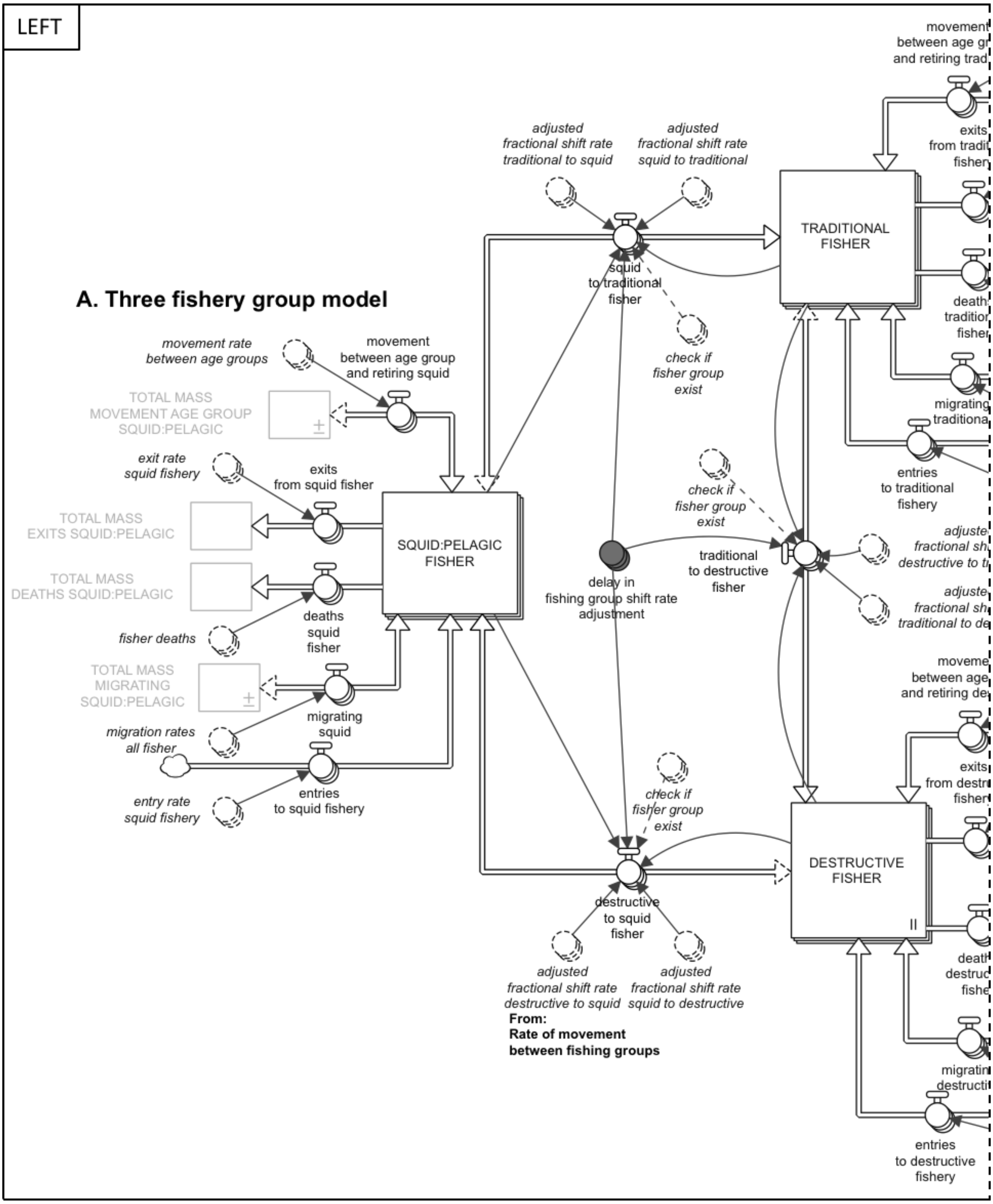


Figure 1-48. Left

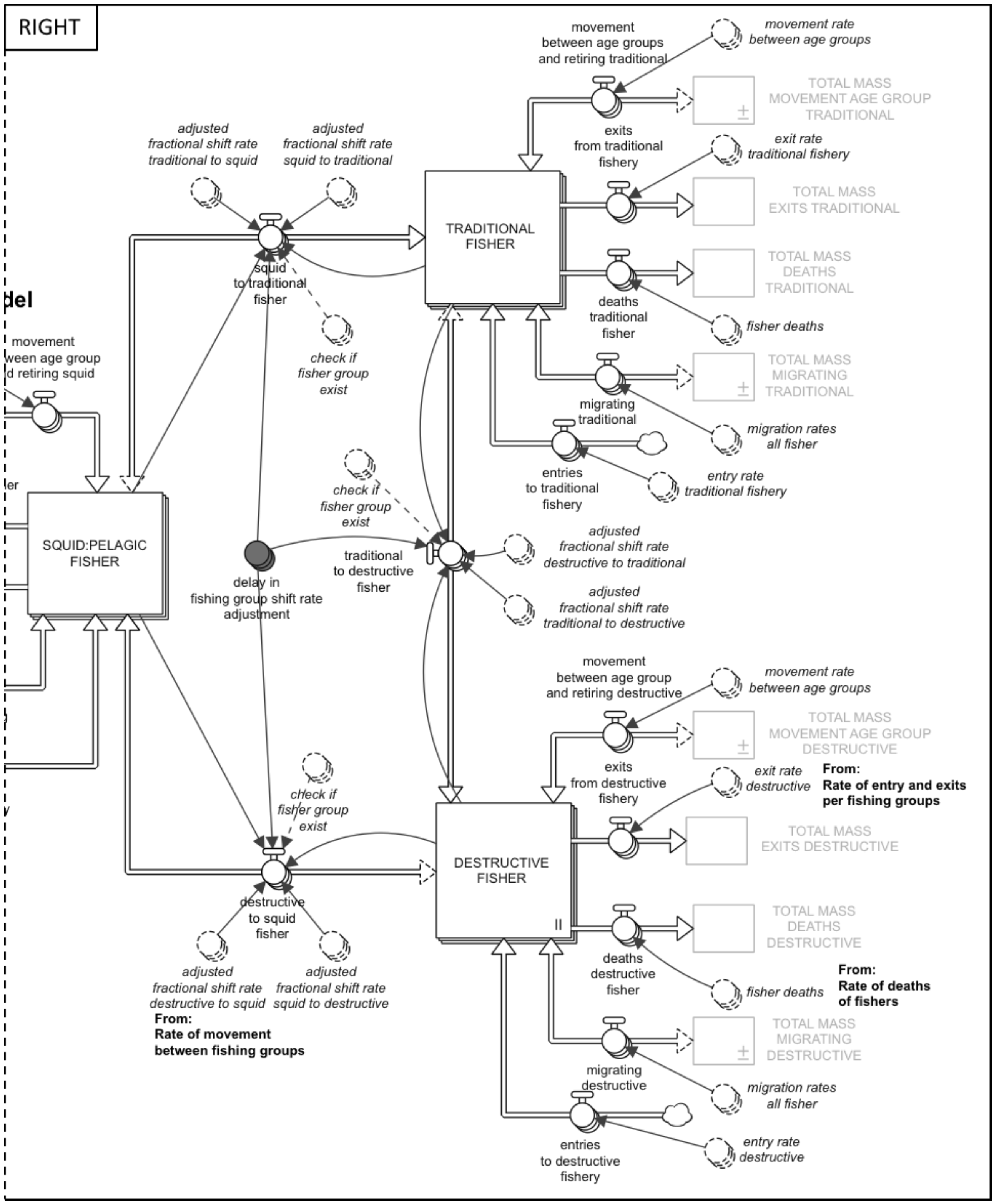


Figure 1-49. Right

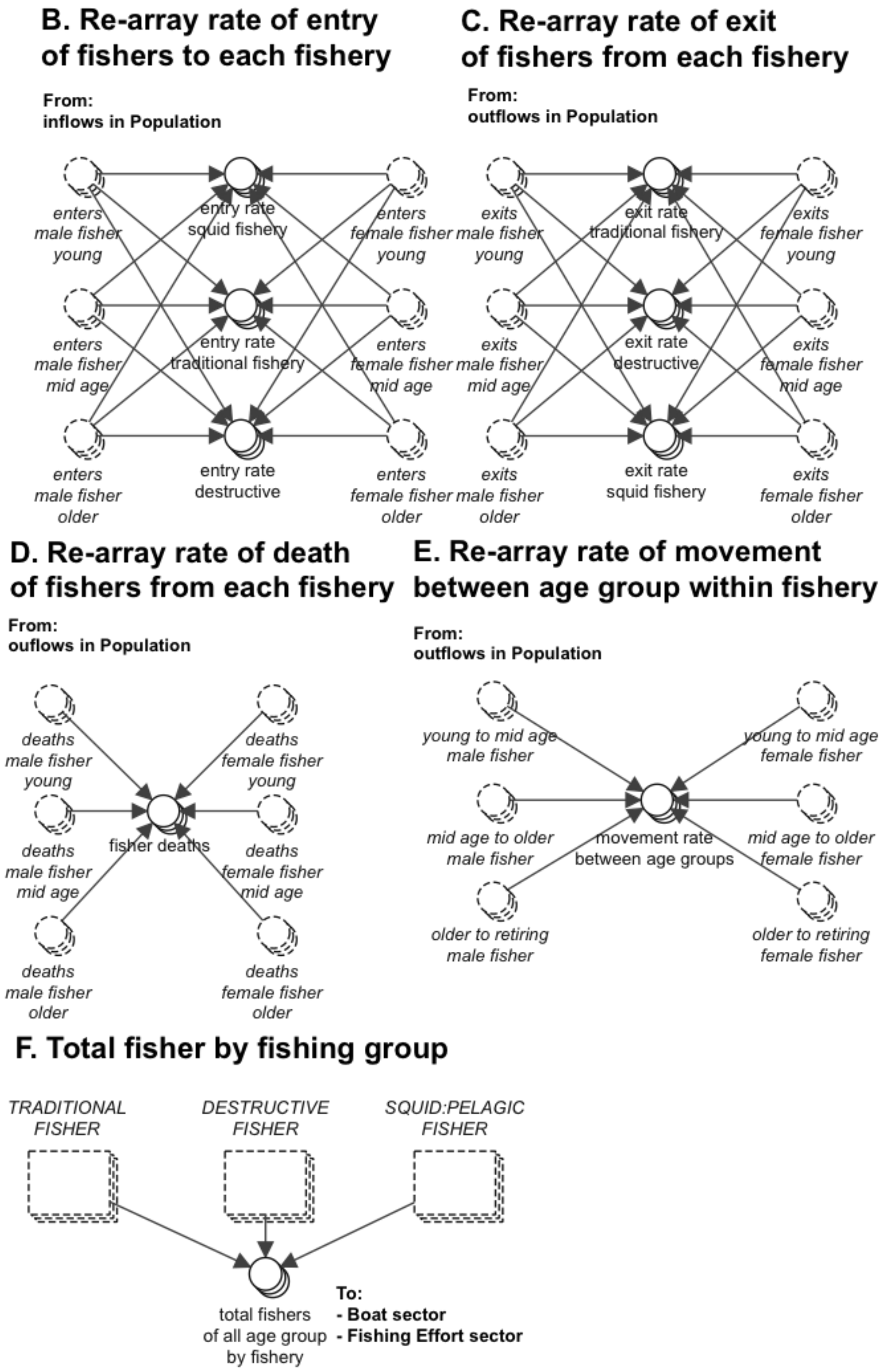


Figure 1-50. Segment 17-A

Sector 18: Adjusted inter-fishery movement and fisher entries and exits

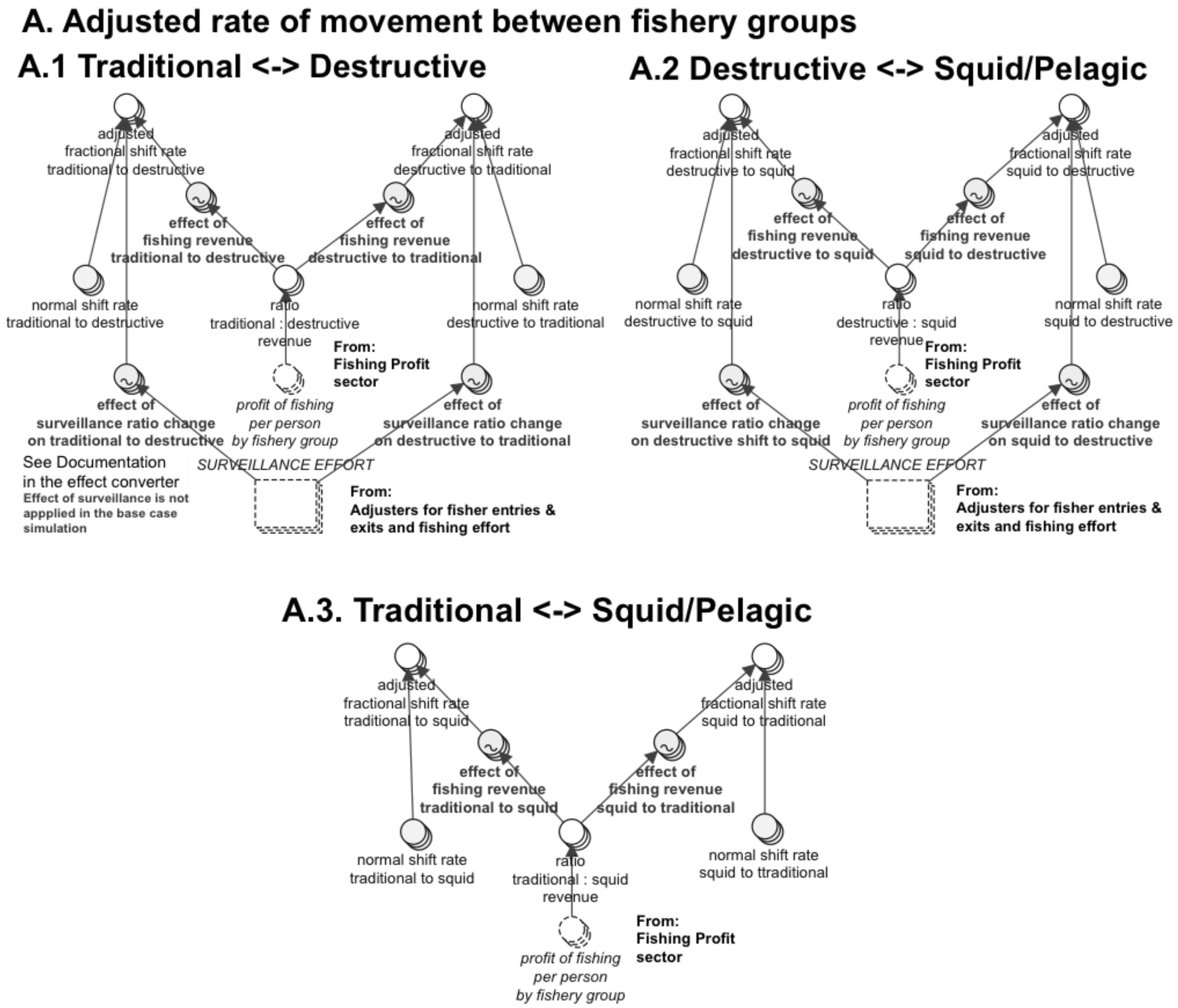


Figure 1-51. Segment 18-A

B. Adjusted rate of fishing labor entering to and exiting from fishery

B.1 Rate of entry to fisheries

B.2 Rate of exit from fisheries

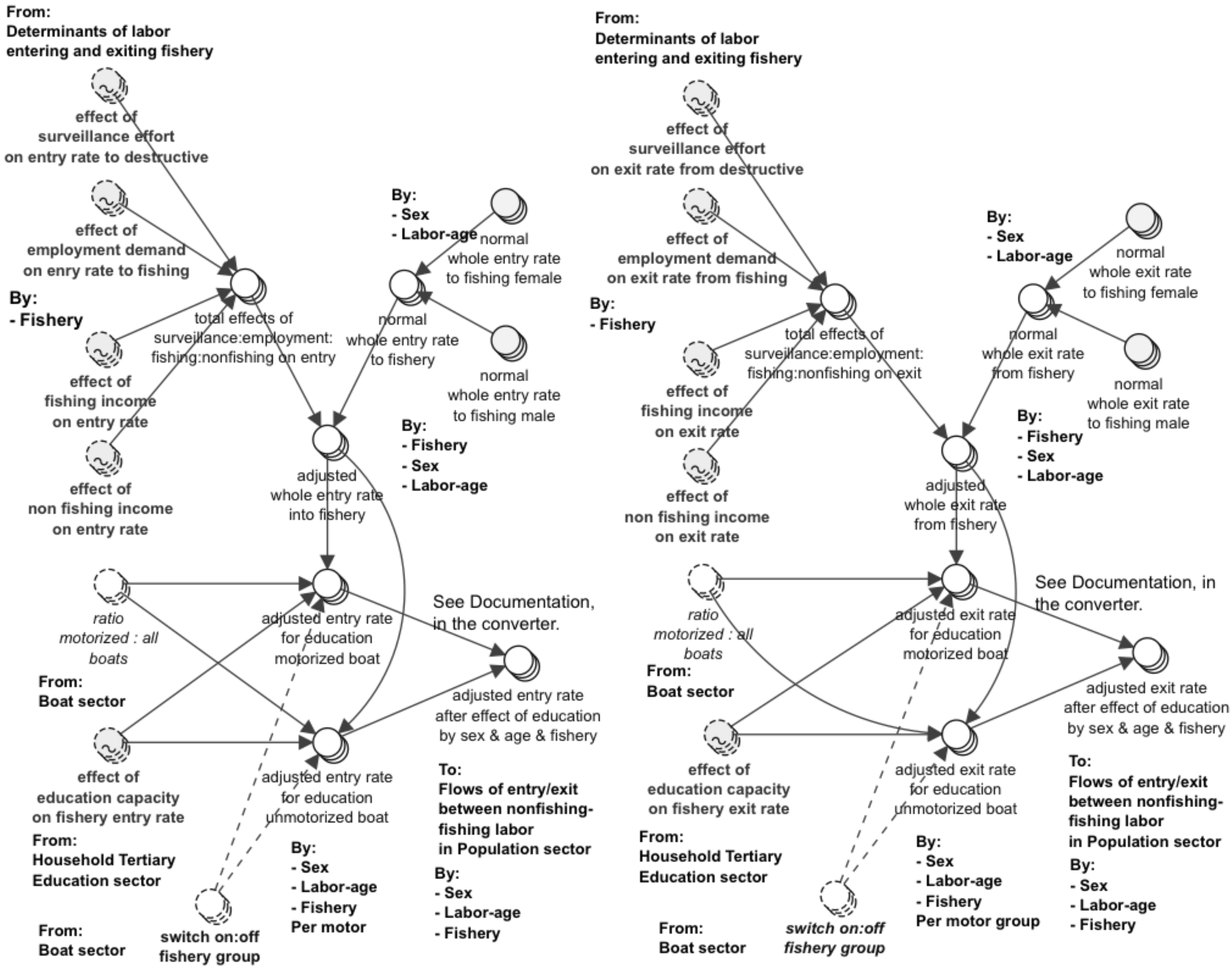


Figure 1-52. Segment 18-B

Sector 19: Determinants of fisher entries & exits and fishing effort

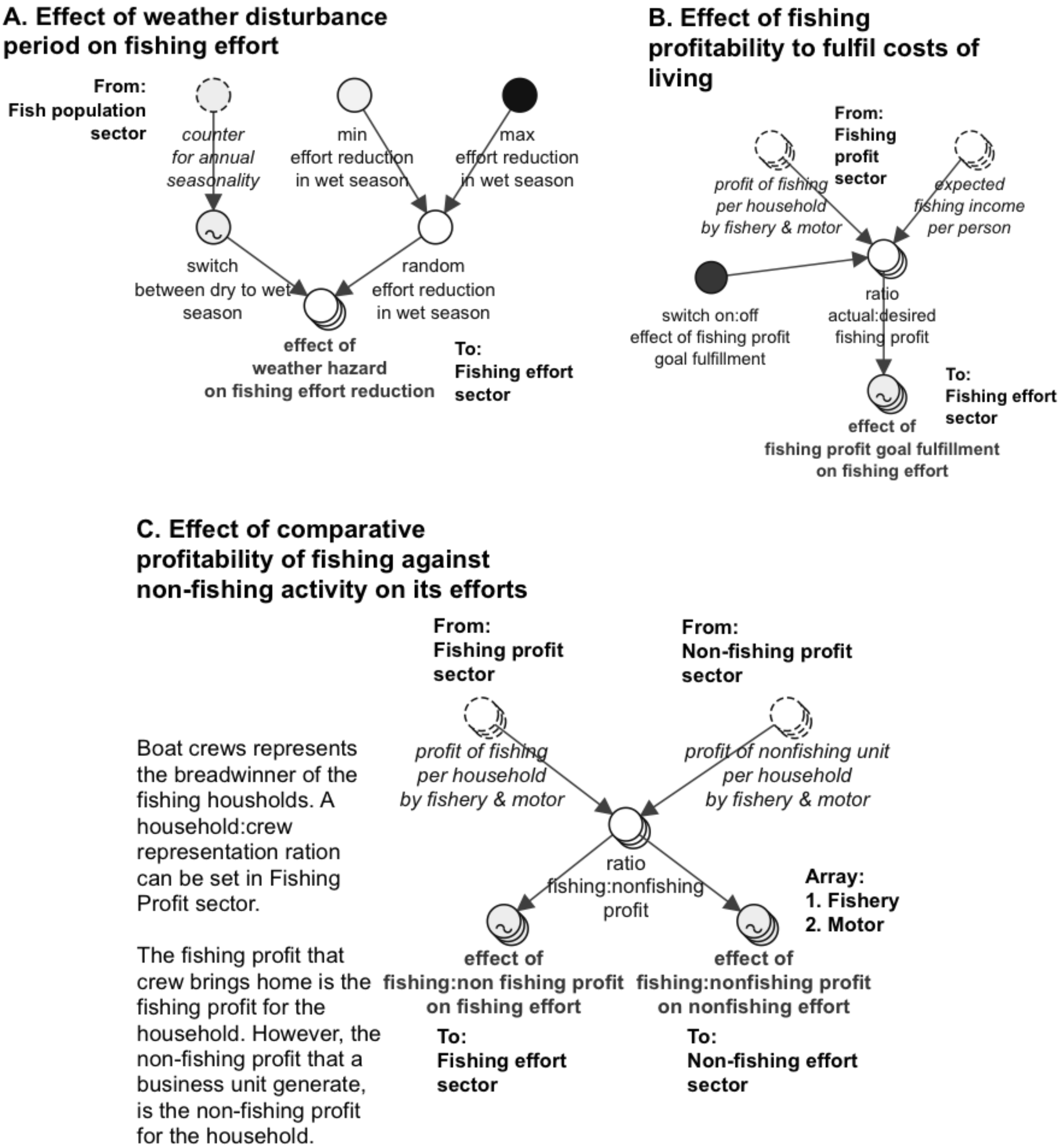


Figure 1-53. Part A, B, C in segment 19-A

D. Effects of profitablity of fishing against non-fishing on entries & exits

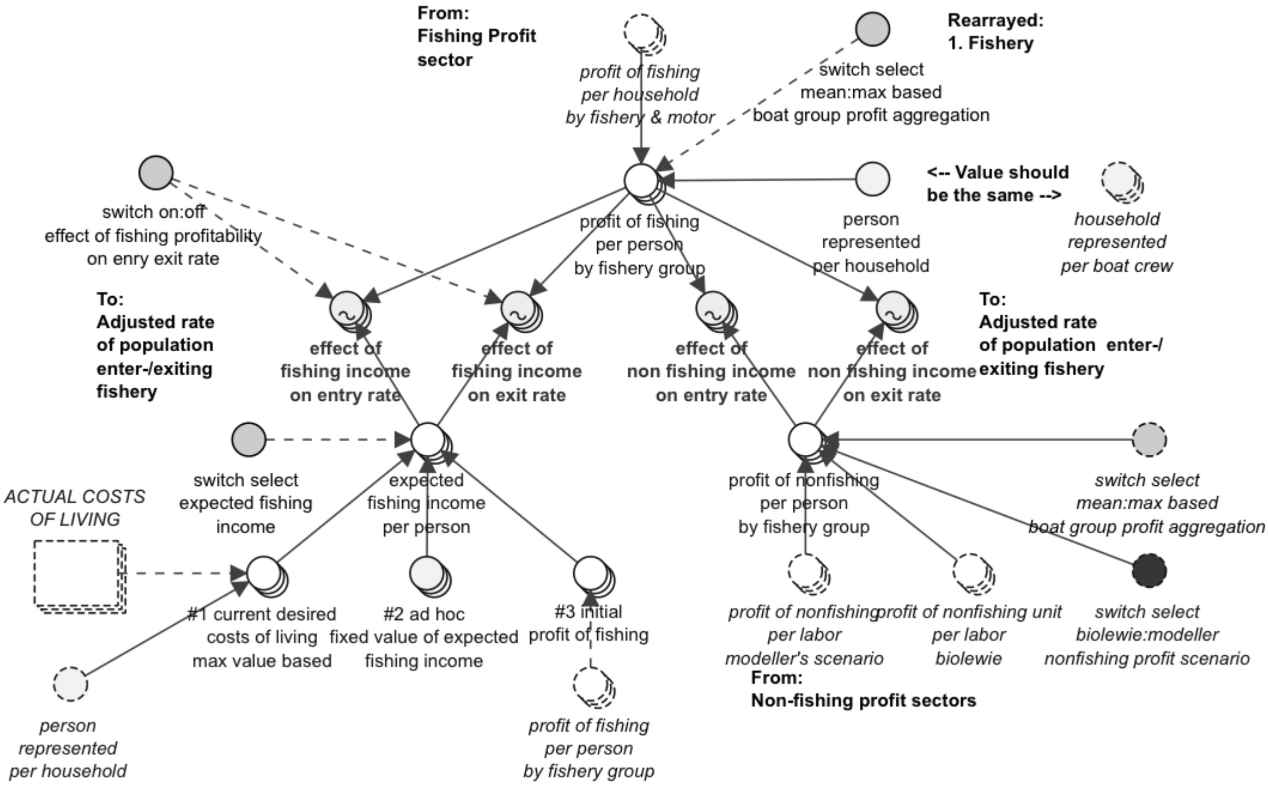
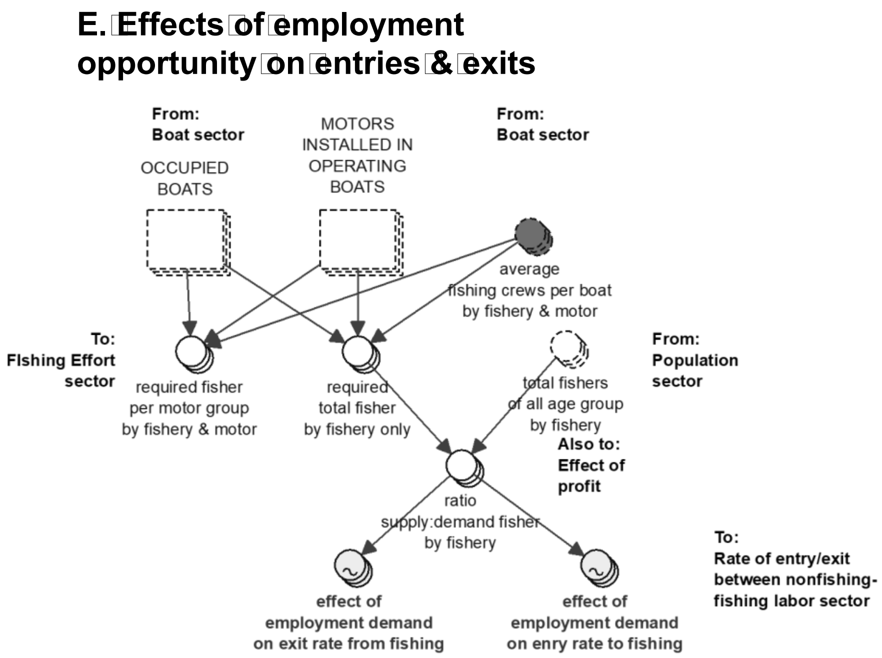


Figure 1-54. Part D, in segment 19-B



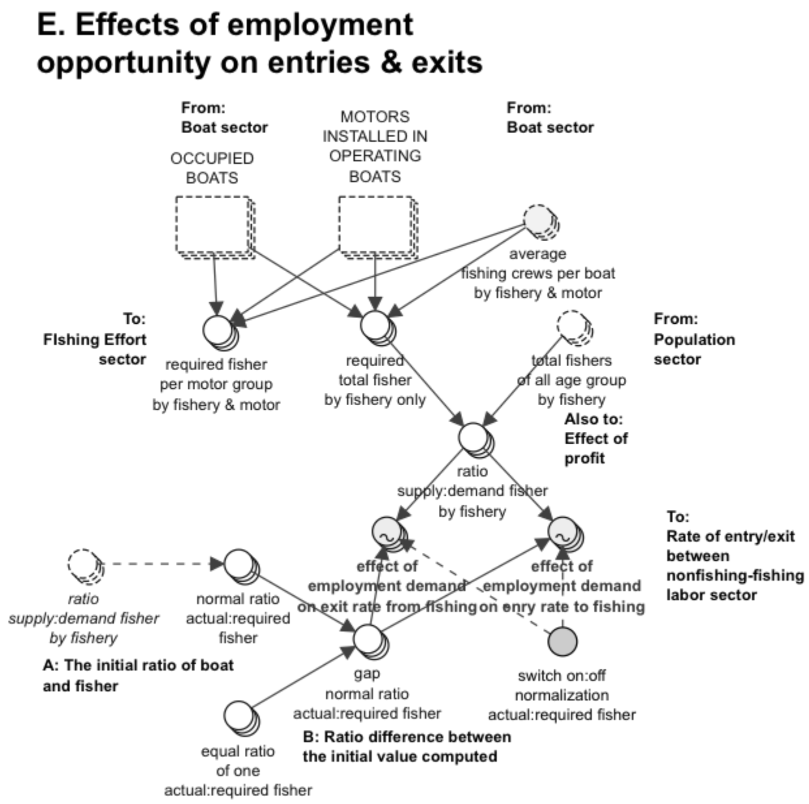


Figure 1-55. Part E, F in segment 19-C

Sector 20: Household loan and debt

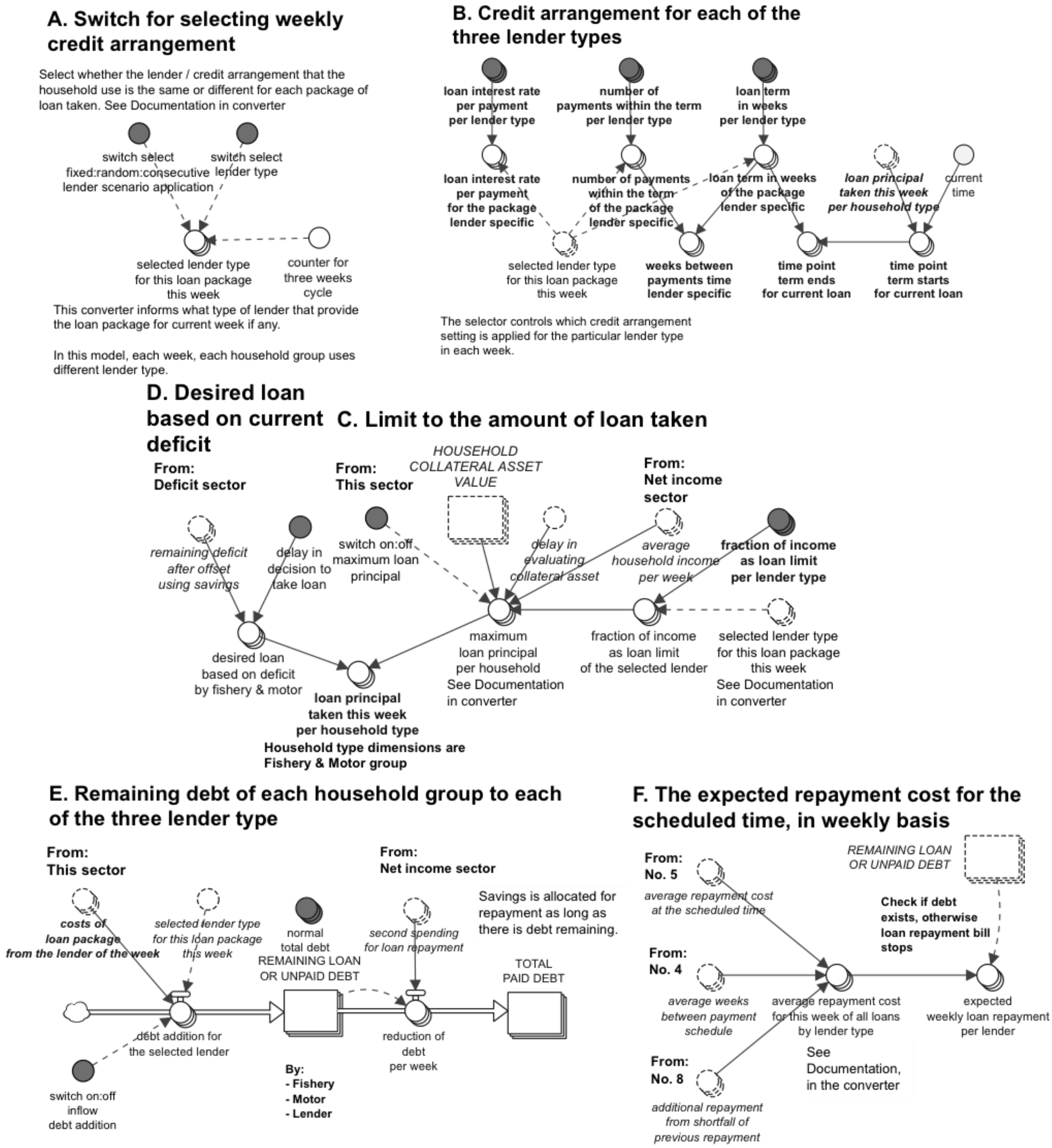


Figure 1-56. Segment 20-A

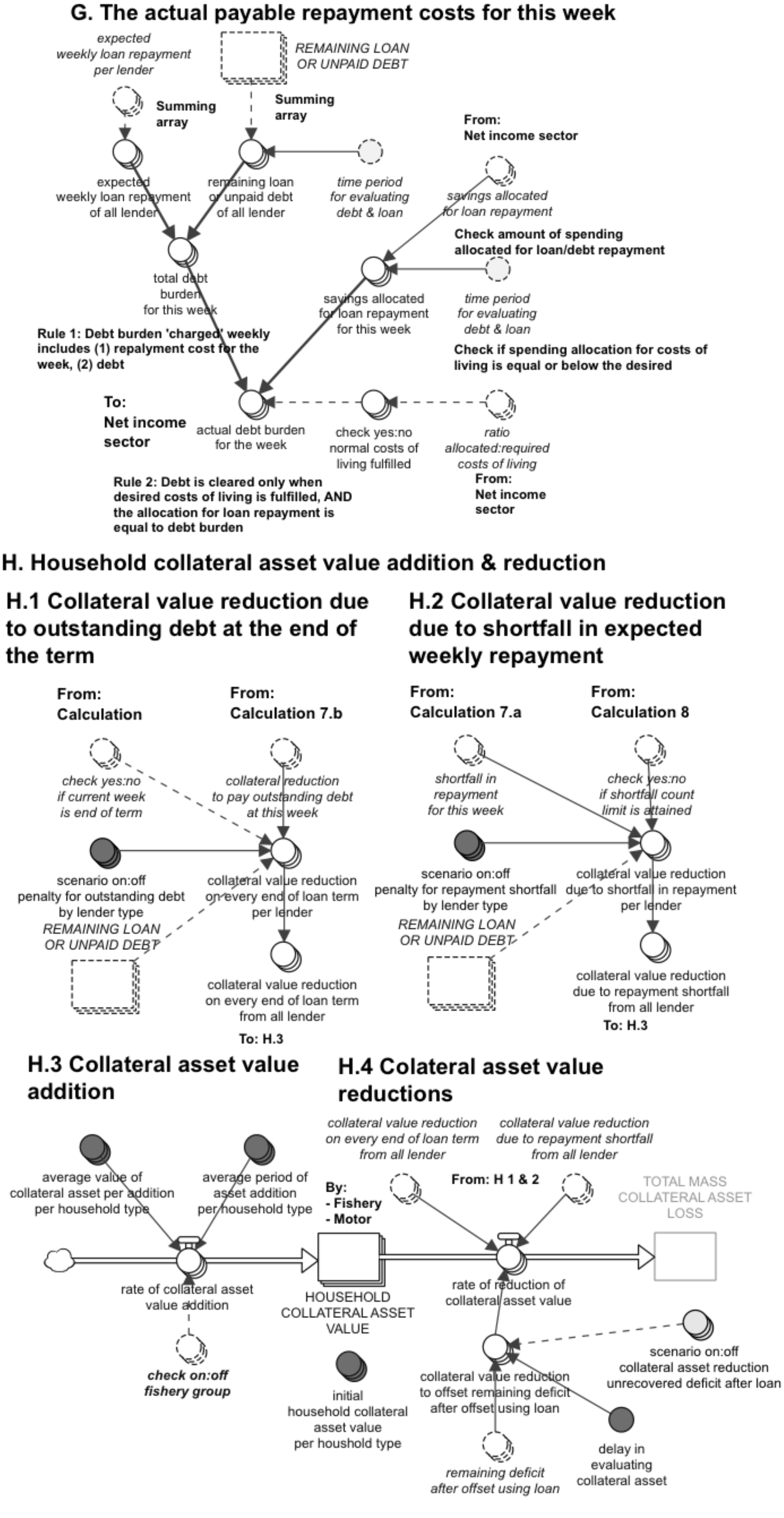


Figure 1-57. Segment 20-B

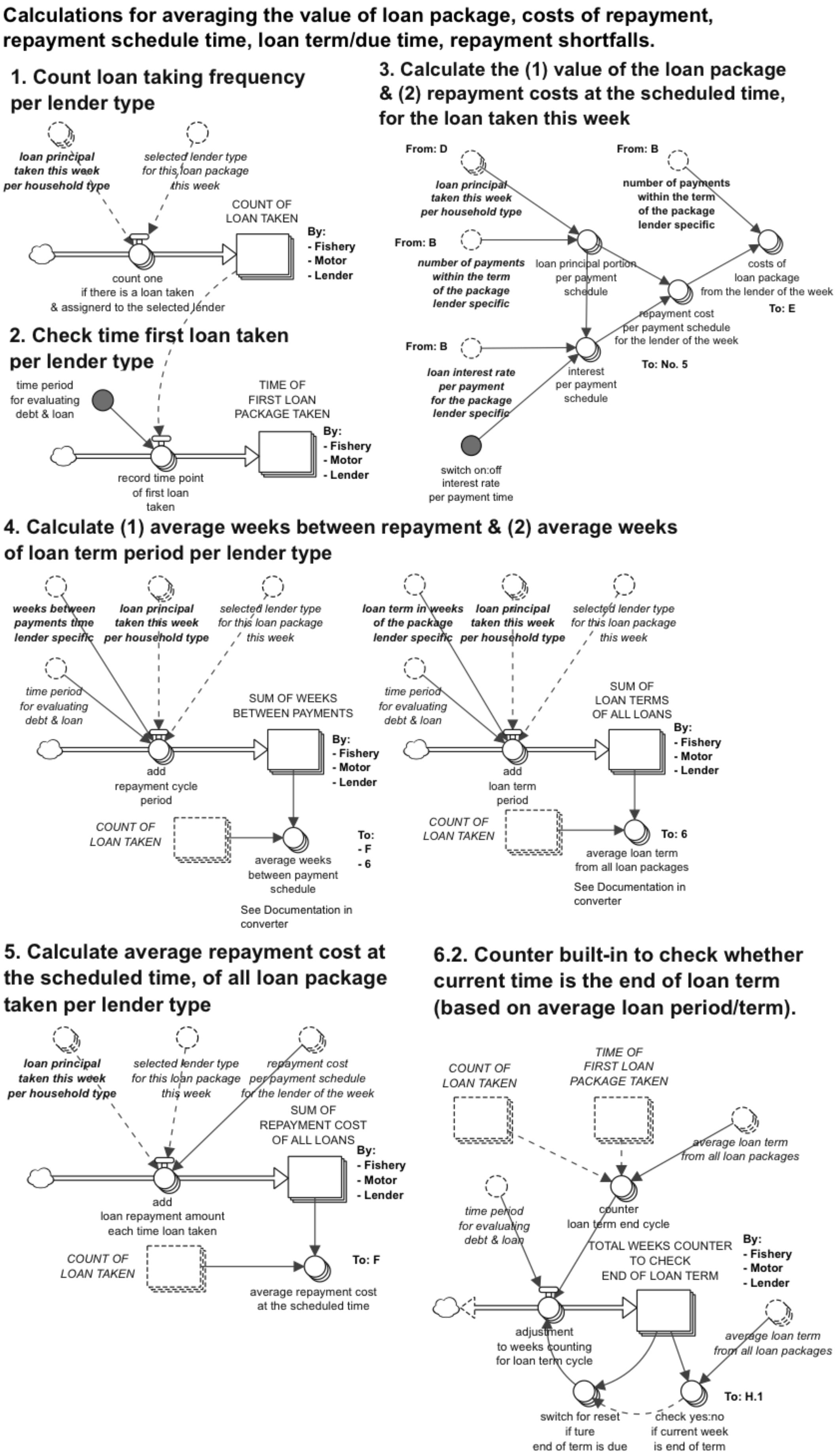


Figure 1-58. Segment 20-C

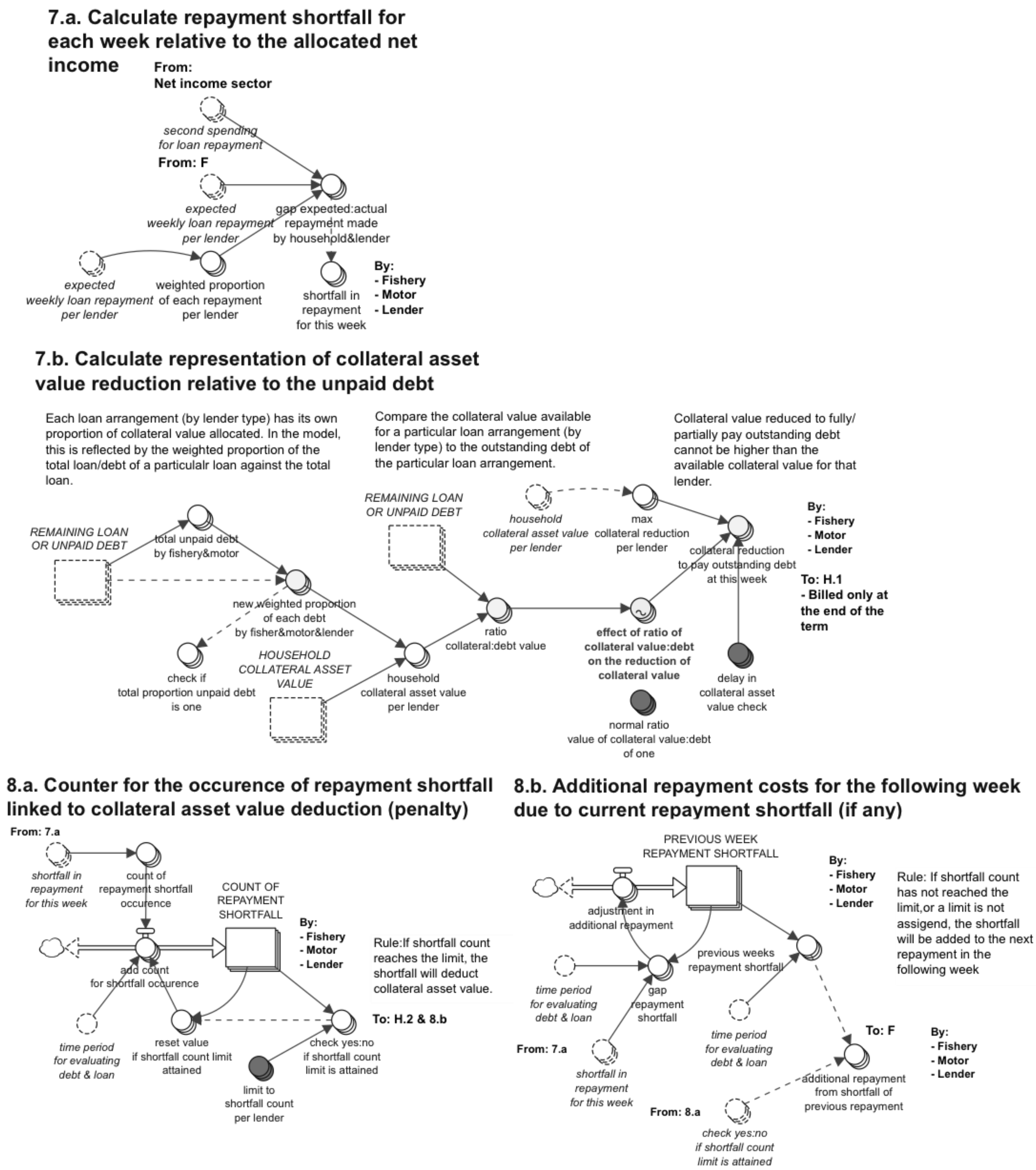


Figure 1-59. Segment 20-D

Appendix 19. Stella® equations contained in the converters

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

https://espace.library.uq.edu.au/view/UQ:a40c1f6/appendices.pdf

or obtained via email request to the author at: siham.afatta@uqconnect.edu.au

Appendix 20. Stella® equations contained in the flows

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

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or obtained via email request to the author at: siham.afatta@uqconnect.edu.au

Appendix 21. Stella® equations contained in the stocks

Due to the PhD thesis word and page limit, the content of this appendix is available as a Portable Document Format that can be downloaded from:

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or obtained via email request to the author at: siham.afatta@uqconnect.edu.au

Appendix 22. Initial input values contained in the stocks

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Appendix 23. Stella® equations contained in the graphical converters

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Appendix 24. Initial input values contained in the constant converters

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Appendix 25. Input values contained in the switch converters

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Appendix 26. Multiplier values applied using converters during the calibration of the base-case parameterisation

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Appendix 27. Results of the mass-balance test

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Appendix 28. Results of the extreme conditions test

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Appendix 29. Results of the sensitivity test

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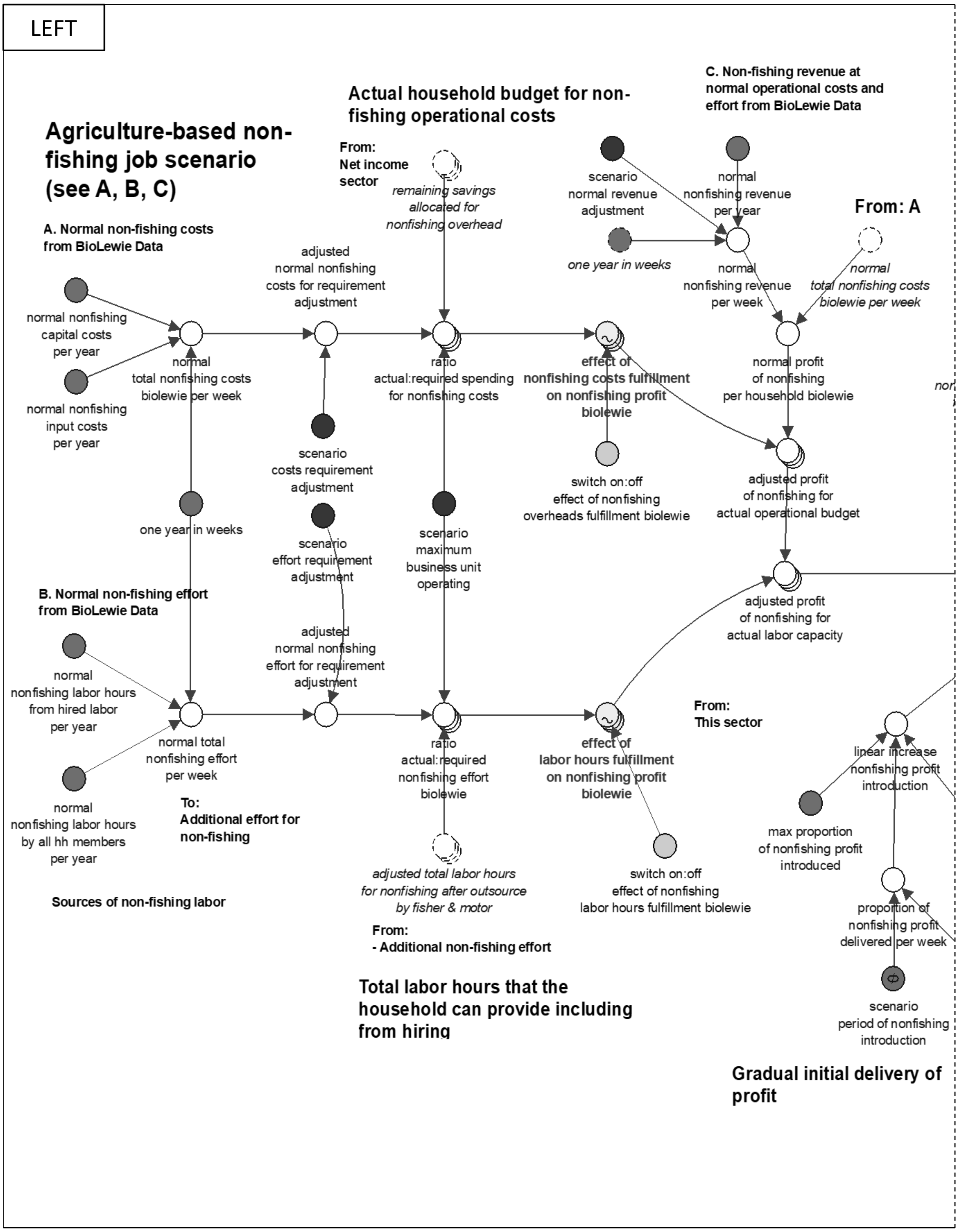
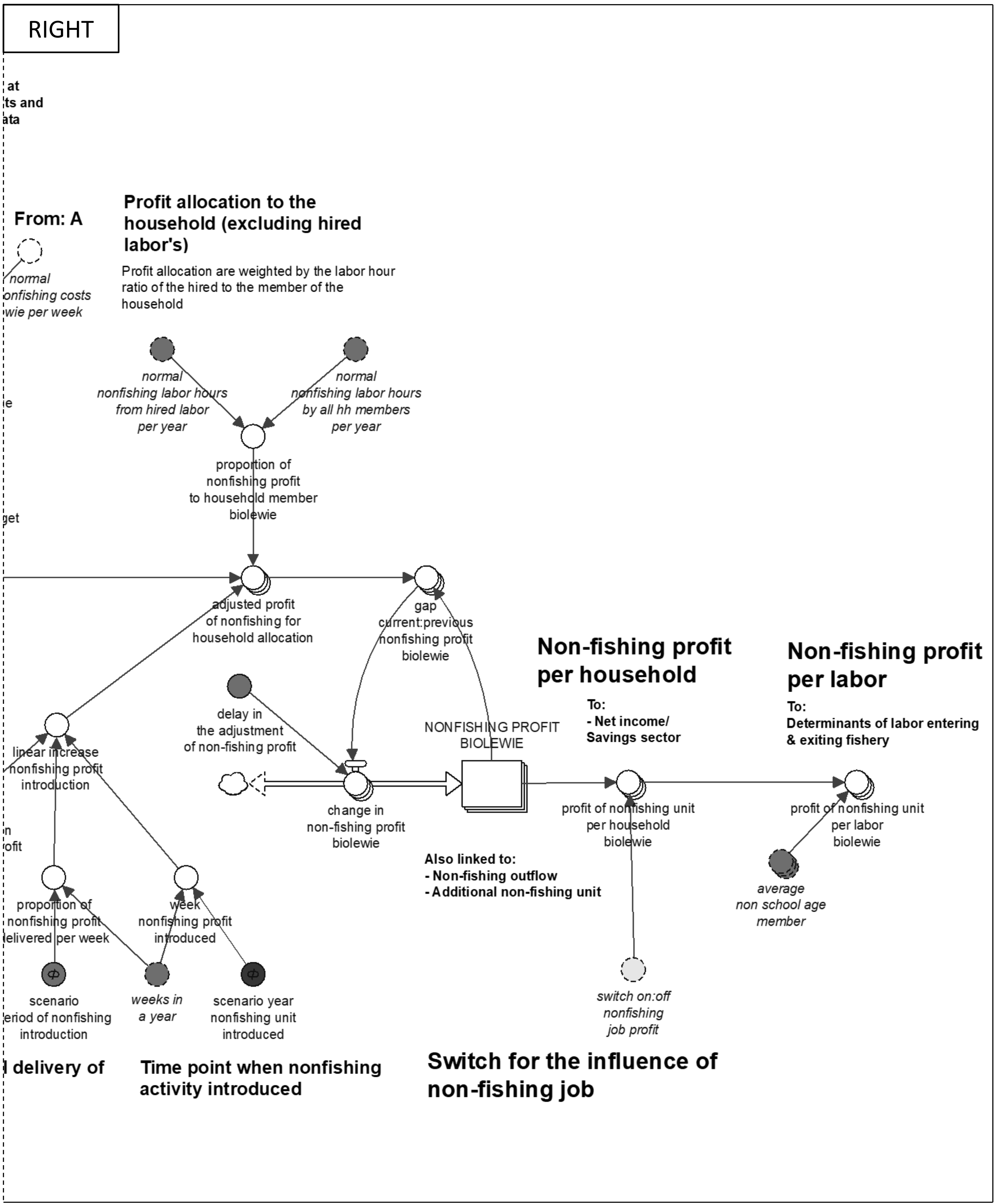
Appendix 30. The Policy 1 stock-and-flow diagram represented in the Stella® Architect software and the embedded equations

Stock-and-flow diagram of Policy 1





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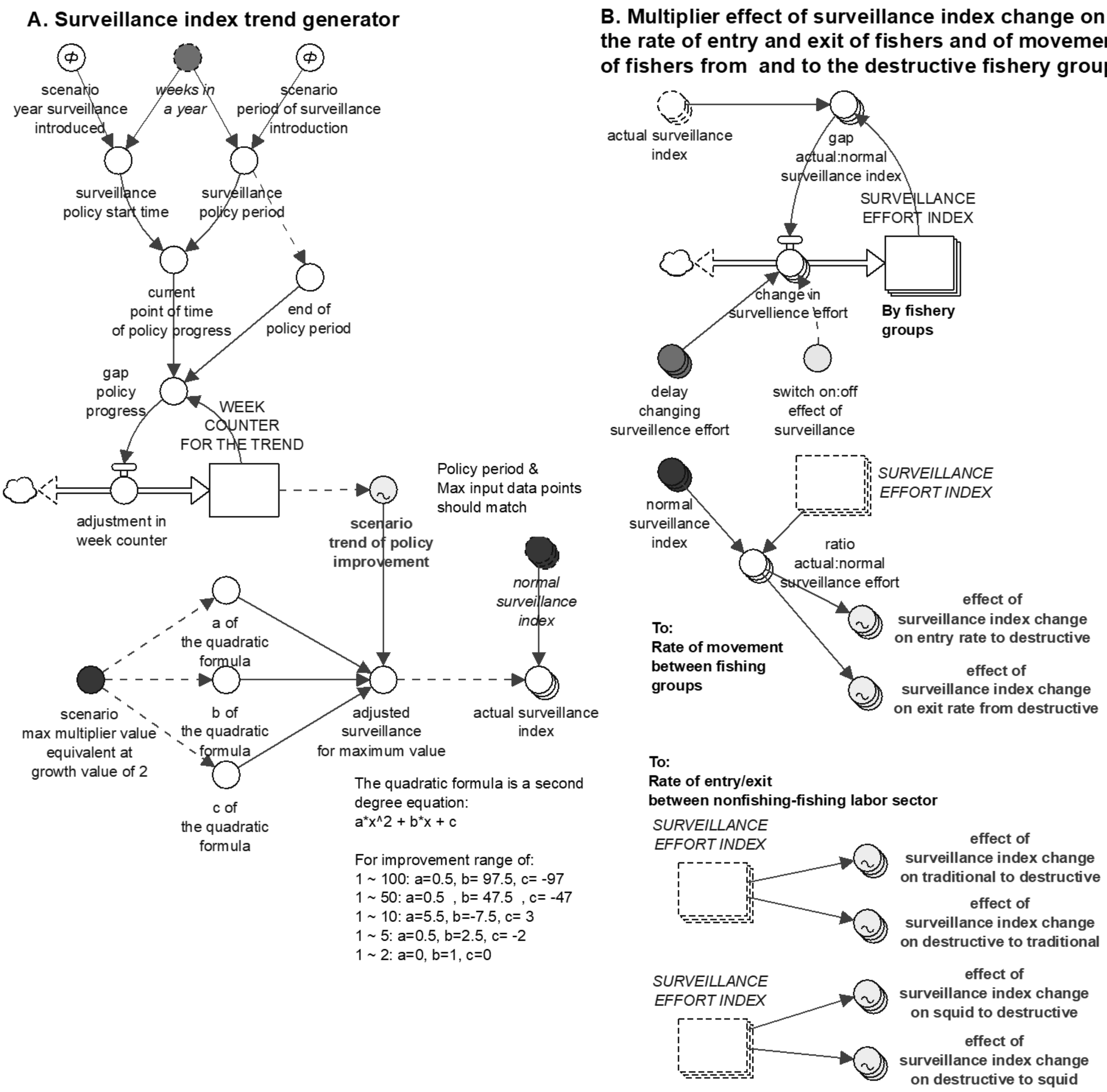
Appendix 31. The Policy 2 stock-and-flow diagram represented in the Stella® Architect software and the embedded equations

Stock-and-flow diagram of Policy 2



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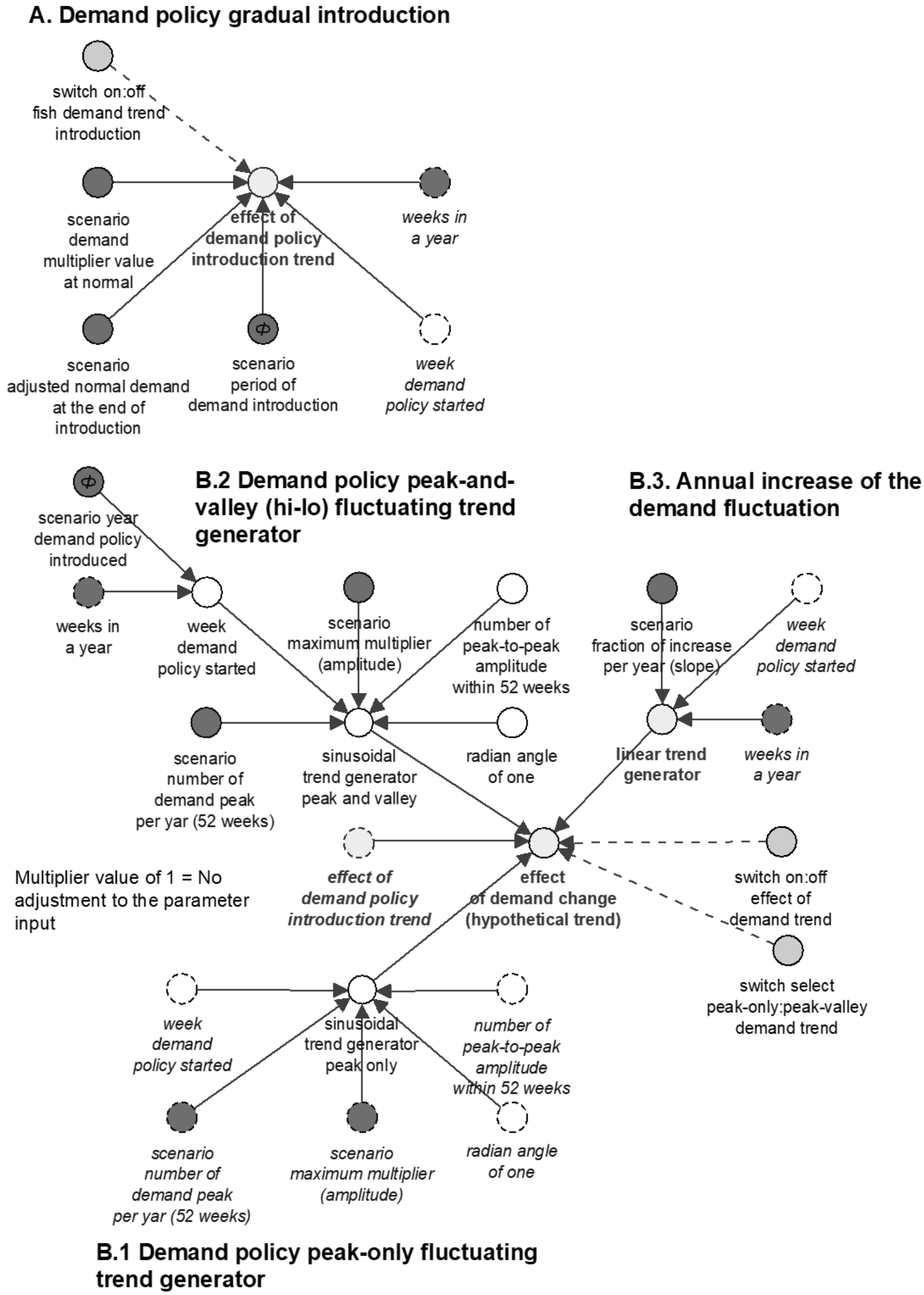
Appendix 32. The Policy 3 stock-and-flow diagram represented in the Stella® Architect software and the embedded equations

Stock-and-flow diagram of Policy 3



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